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W. G. FARLOW













# FERTILIZER RESOURCES OF THE UNITED STATES

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MESSAGE FROM THE  
PRESIDENT OF THE UNITED STATES

TRANSMITTING

A LETTER FROM THE SECRETARY OF  
AGRICULTURE, TOGETHER WITH A PRE-  
LIMINARY REPORT BY THE BUREAU OF  
SOILS, ON THE FERTILIZER RESOURCES  
OF THE UNITED STATES



DECEMBER 18, 1911

Read; referred to the Committee on Agriculture and Forestry and ordered to be  
printed with accompanying illustrations

WASHINGTON  
1912

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## MESSAGE OF THE PRESIDENT.

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*To the Senate and House of Representatives:*

I transmit herewith, for the information of the Congress, a communication from the Secretary of Agriculture, accompanying a preliminary report on the fertilizer resources of the United States. This report carries valuable data and information of great public interest, and I am in hearty accord with the recommendation of the Secretary that this work receive all the support which Congress in its wisdom may find expedient to give to it.

WM. H. TAFT.

The WHITE HOUSE, December 18, 1911.





## LETTER OF TRANSMITTAL.

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DEPARTMENT OF AGRICULTURE,  
OFFICE OF THE SECRETARY,  
*Washington, December 14, 1911.*

MR. PRESIDENT:

I have the honor to transmit a preliminary report on the fertilizer resources of the United States, describing investigations which have been carried out by experts of the Bureau of Soils, following a special authorization by the last regular session of Congress. This work is now in progress. But the ground already covered and described in this report is of such public interest that I am impelled to lay it before you at once.

The use of fertilizers has grown to very large proportions in this country, involving an annual expenditure of about \$120,000,000, and there are many evidences that this amount is likely to be soon increased several fold as more modern and intensive agricultural methods are adopted, these being a necessary consequence to the rapid settlement of the country and the inevitable readjustment of social and economic conditions incident thereto.

This country has been supplying its own needs and exporting large amounts of phosphates abroad. It appears from the evidence in this report that the supplies of natural phosphates at present in sight will be sufficient for our needs for 10 centuries or more, if they are exploited carefully and with a minimum wastage. But it is clearly evident that the wastage must be stopped or controlled, if we are to maintain our independence in this regard. Methods for the utilization of lower-grade materials and improvement of the manufactured product must be worked out, and this report contains valuable data toward these ends. A marked tendency toward better and less wasteful methods of mining is already in evidence. There has been some public alarm, not only on account of the large shipments of phosphate rock to foreign ports, but also on account of some large holdings of phosphate lands passing into the hands of foreign owners. From this report, however, it appears that by far the major part of the holdings are in American hands, and the tendency is distinctly toward an increase in this direction. At present the domestic consumption of phosphate rock is about 2,650,000 tons. The exportation is about 1,100,000 tons, valued at about \$8,250,000. The estimated amount of high-grade rock and its equivalent in lower grades is about 9,500,000,000 tons.

Not so fortunate has been our situation with regard to nitrogenous and potash fertilizers, and recent events have tended to create more

or less alarm regarding our dependence on foreign sources of supply. But the evidence brought together in this report shows that ample supplies of both classes of fertilizers can readily be obtained from American sources, and in the case of the potash the supply may be maintained indefinitely if obvious methods of control are promptly instituted. One of the important sources of nitrogenous fertilizers is the ammonium sulphate obtained from modern types of coke ovens and gas works. Calculated from the coal used in these industries, the annual production of ammonium sulphate should be approximately 640,000 tons, valued at \$30,000,000. Actually 35,000 tons, valued at \$1,840,000, are being produced, while about 104,000 tons, valued at \$5,300,000, are annually imported.

Investigations have been made and are still under way for the extraction of potash from silicate and other minerals, and from industrial wastes and by-products. Likewise diligent search is being made of the desert basins of the arid States. Some promises of minor successes are coming from this work. But in the giant kelps of the Pacific coast there is a potential source of potash salts which can certainly yield annually some three or four times the amounts now used in this country, and under the best management might even rival the famous Stassfurt deposits. It is regarded as a very conservative estimate to put the annual yield of potassium chloride from the Pacific kelps at upward of 1,000,000 tons, worth at present prices nearly \$40,000,000. Some very important problems regarding the harvesting of the kelp and the technical handling of the product are not yet worked out completely. These do not appear to present any serious difficulties, however, and with a little more time and the support of Congress it seems certain that a notable addition will be made to American industries, and a valuable resource made available to American agriculture. It is obvious that the investigations described in this report are a public work of fundamental importance to the general welfare.

I have the honor to recommend that this report be transmitted to Congress, together with the maps, illustrations, and diagrams accompanying, to be printed by order of that body, and I further recommend that not less than 5,000 copies be printed for the use of this department, in addition to such number as Congress may order for the use of its Members.

I have the honor to remain, Mr. President,

Very respectfully,

JAMES WILSON, *Secretary.*

## LETTER OF SUBMITTAL.

---

UNITED STATES DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS,  
*Washington, D. C., December 13, 1911.*

SIR: I have the honor to submit herewith the manuscript of a preliminary report on the fertilizer resources of the United States. At the last regular session of Congress, and at the instance of the Hon. A. F. Lever, special authority and a specific appropriation was given for the investigations described in this report, it being understood that the necessary laboratory work would be provided in the already existing organization of this bureau. The bureau has, moreover, been fortunate in securing the services of a number of experts who would not ordinarily be available to the department and to whom acknowledgment is made in the accompanying manuscript.

The scope of the investigations is very wide, and much valuable information has been acquired which will later be of incalculable value to the country and of great assistance to both scientists and laymen who are interested in fertilizers. Valuable work has been done in the investigation of sources of supply and the manufacture of phosphatic and nitrogenous fertilizers. Most important, however, and especially so because of recent public events, are the results of the investigations on possible sources of potash fertilizers. While there are several sources of potash of possible economic importance, one of these overshadows all others. In the kelp groves or beds of giant kelps along the Pacific littoral, and especially in the large groves of *Macrocystis* from Point Sur southward, the United States possesses an extremely valuable national asset. At their best, and under the most careful and efficient utilization of these groves, they might be made to yield annually an output of potassium chloride approximating the production of potash salts of all kinds from the world-famous Stassfurt deposits. But until more complete studies have been made it seems wise to advance a more conservative estimate. From the observations and data which this bureau has recently secured there can be no reasonable doubt that the Pacific kelps may easily be made to produce annually potassium chloride to the extent of at least three times the present importations of potash salts of all kinds, with a value, at current prices, between \$35,000,000 and \$40,000,000. Moreover, it should be perfectly feasible to cover

most, if not the entire, cost of production of this vast "crop" by the iodine and other by-products produced simultaneously.

So important are these facts for the national welfare, and so acute is public interest in them, it is deemed wise to submit this preliminary report at the earliest date practicable, that you may make such disposition of the information as may commend itself to your judgment.

I have the honor to be, Mr. Secretary, respectfully,

MILTON WHITNEY,  
*Chief of Bureau.*

HON. JAMES WILSON,  
*Secretary of Agriculture.*

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# **A PRELIMINARY REPORT ON THE FERTILIZER RESOURCES OF THE UNITED STATES**

**BY**

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**WITH THE ASSISTANCE OF**

**R. B. MOORE**

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## A PRELIMINARY REPORT OF THE FERTILIZER RESOURCES OF THE UNITED STATES.

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### THE PURPOSE AND SCOPE OF THE WORK.

#### READJUSTMENT OF LAND VALUES.

There are yet many unoccupied acres of arable land in the United States. This is true of the East as well as the West and of the North as of the South. But the time for pioneer invasion of virgin territory is past. In a broad way the country is now settled. Already the readjustment of population, the necessary consequence of this settlement, is under way, and the return tide of immigration from the West to the East is beginning to attract public attention.

With the readjustment of the population there must inevitably come a readjustment of land values. Generally speaking, the values of arable lands west of the Mississippi River are much higher than the values of land east of that river. The one stable basis for determining land value is its productivity measured in crops. While undoubtedly having an influence locally on relative values, the productivity of the soil has not, up to the present, been the determining factor in adjusting the relative values throughout the country as a whole, or even throughout the major sections of the country.

The readjustment of land values is inevitable. A rapid movement in this direction might easily bring dire results, economical and social. It is the duty of the Federal Government, and it is a major effort of the Department of Agriculture, to determine existing conditions, that there may be a more gradual movement founded on well-ascertained facts and a better understanding of our soils and their productive capacities under intelligent management and control. Soil surveys and agronomic investigations by Federal and State agencies are rapidly accumulating fundamental data of incalculable value. But a sufficiently complete and satisfactory knowledge of the possibilities of our soils under the best conditions can be claimed for only a very few special cases.

The experience of the world, confirmed and emphasized by recent scientific investigation, has shown conclusively that efficient utilization of the soil involves the coincident employment of tillage, crop rotations, and soil amendments, or fertilizers. In our South Atlantic States, because of the former slave labor, which understands the cultivation of but one or two crops, and because of the distressing labor conditions following the Civil War, one-crop systems prevail. The introduction of commercial fertilizers soon after the war was eagerly hailed as a universal panacea, and tillage generally was negligent and of the most unsatisfactory character. An enormous fertilizer

business was built up, but the abused and misused soils became a reproach, and the "worn-out soils" of the South a byword. Recent developments, however, among which the advance of the boll weevil stands prominently, have led to the introduction of diversified farming in many localities. That is to say that, in addition to using fertilizers freely, they have been used more intelligently; the adaptation of crops to types of soil has been considered; rotations introduced; better tillage employed; and it is rapidly becoming evident that the "worn-out" soils of the South, under intelligent management, compare favorably with those of any section.

In the trans-Mississippi regions, because of their rapid settlement, pioneer methods of agriculture have retained a great influence. Here again the one-crop system has prevailed, crop rotations have been unusual, fertilizers are seldom or never employed, and on tillage alone has dependence been placed. There is a widespread and rapidly growing belief that the soils of many sections are falling off in productivity, and that the yields now obtained will not justify a continuance of the existing high valuation of the land. Clearly, to maintain a high crop production and efficient use of the land, suitable crop rotations must be determined and employed and an intelligent use of fertilizers developed. Local prejudices must yield and will do so the more readily as population increases and local transportation facilities are developed.

The widespread and general introduction of such agencies as the telephone and the automobile into western areas is rapidly bringing about a disintegration of "ranches" into farms and the introduction of modern intensive methods. There exists a strong local prejudice in many sections of the country to the use of fertilizers, because of a popular concept that their only or main function is to supply "plant food," and that the admission that they are beneficial to the soil is tantamount to an admission that the soils are "wearing out." Scientific investigations of the last few years, however, have shown that fertilizers have many other and probably more important uses than increasing the supply of mineral plant nutrients, and the general spread of this knowledge among our agricultural people will go far to overcome this unfortunate local prejudice.

The readjustment of land values, then, is a great national problem, dependent upon a better use of the land, involving the general introduction of intensive methods of agriculture, including a rational management of the soil through the human instrumentalities of tillage, crop rotation, and fertilizers. Tillage and crop rotations are mainly problems within the control and dependent only upon the judgment of the farmer himself. Fertilizers, however, involve problems of quite different character, bringing the farmer into contact with those of manufacture, distribution, sources of supply, etc., which obviously call for governmental assistance.

#### FERTILIZERS.

At present about \$120,000,000 annually is spent in this country for commercial fertilizers, of which more than 80 per cent is spent in the South Atlantic States and about 3 per cent west of the Mississippi River. The use of fertilizers in Texas, Mississippi, and the citrus-fruit regions of California has been increasing rapidly, however, in

the last few years. With the development of the use of fertilizers in the older sections of the country and the certainty of its extension into the agricultural sections of the West, a vast industry must come into existence in the next few years, of fundamental importance to the agricultural interests and to the material development of our people.

At the present time commercial fertilizers are composed of three classes of material. The basis of artificial or manufactured fertilizers the world over is superphosphate, made by treating with acid, usually sulphuric acid, some natural phosphate, usually a phosphorite or basic phosphate of lime. This country is fortunate in having within its confines enormous deposits of natural phosphates, including the well-known fields of South Carolina, Florida, Tennessee, Arkansas, and Kentucky, lesser deposits in many other States, and the greatest deposit of the world in Montana, Wyoming, Utah, and Idaho.

The second class of fertilizer materials includes the nitrogen carriers. From some points of view the most important of these is sodium nitrate or Chile saltpeter. Last year about 546,525 tons of this material, valued at \$17,101,140, was imported into this country, mainly from Chile. Only a portion, however, variously estimated from 15 to 60 per cent, went into fertilizers. Powder works, the dye and other industries absorbed large quantities of this substance. Deposits of this material have been found in this country, but none of commercial importance have yet been exploited. Ammonium salts, a product of the coke ovens and gas furnaces; slaughterhouse products; cottonseed meal; and in lesser quantities, other nitrogenous organic materials are utilized in the manufacture of fertilizers. The so-called atmospheric products, calcium cyanamid and basic calcium nitrate, are finding an increased use.

Fertilizer materials of the third class are the potash carriers, and practically these are confined at present to the potassium salts coming from Stassfurt, Germany, the mines of which supply the entire world. A relatively small quantity of potassium nitrate from India is imported into this country, but this goes almost entirely into the manufacture of fireworks and explosives. Potassium carbonate in the form of hardwood ashes comes into this country from Canada, a part being used by the fertilizer trade and a part being taken by soap makers. Up to the present there have been no sources of potash in this country commercially developed.

#### AUTHORITY FOR INVESTIGATIONS.

The Bureau of Soils has for some time past given attention to the resources of this country in possible sources of fertilizer materials. Public attention has been repeatedly drawn to this matter in recent years; first, through fears expressed by some writers in the current press that our resources in phosphates were being unwarrantably dissipated; and, second, by the controversy arising between the German "Kali Syndikat" and certain American importers of potash salts. At the last regular session of Congress, at the instance of the Hon. A. F. Lever, the Bureau of Soils was authorized and directed to explore and investigate this country for sources of fertilizer

materials, and at the same session the United States Geological Survey was given authority enabling it to make exploratory borings to determine the possible existence of segregated layers of potash salts, similar to the deposits at Stassfurt.

The work of the Bureau of Soil, although it has been in progress but a few months, has developed to a point of public interest and importance which calls for the preliminary report which follows.

#### LINES OF INVESTIGATION.

This work has been along several main lines. A field survey of the desert basins in our arid States is in progress, for the purpose of locating deposits of potash salts and nitrate, and incidentally to locate deposits of alunite, leucite, phosphorites, or any materials of importance to the general purpose of the investigation. A somewhat detailed survey has been made of the Otero Basin in New Mexico, of the Surprise and neighboring valleys in Oregon, and of a part of the Salton Basin in California; and less detailed work has been done in a number of localities in these same States and in Nevada.

The Geological Survey is drilling in the Humboldt Basin and carrying on work closely allied to the work of this bureau just described, and the State geological agents of Nevada have been conducting work of a similar character. To avoid duplication of effort and to furnish analytical assistance in the most prompt and practical manner, a cooperative laboratory has been opened at the University of Nevada, at Reno, under the direction of Prof. J. G. Young. This laboratory, besides furnishing assistance to this bureau, the Geological Survey, and the Geological Survey of Nevada, will, in addition and under reasonable restrictions, make examination of samples forwarded by private individuals when the samples are expected to assist in the location of deposits of potash, nitrates, or phosphates.

A second line of investigation is of the brines and bitterns from salt wells to determine the presence of workable quantities of potash. Several hundred samples, a large proportion collected under standard conditions, are now being analyzed with great care.

A third line of investigation has been a study of the effect of water and of various reagents upon the potash feldspars and other potash minerals. Patented and unpatented processes have been subjected to scrutiny and tests to determine their values for utilizing great natural resources and as a measure of protection to the public, which seems unduly prone to invest unthinkingly in "chemical" propositions, and especially in potash ventures. Among other things the efficiency with which potash may be extracted from alunite has been studied, and it seems that under favorable conditions this mineral may become an important source of potash.

A fourth line of investigation has been a theoretical study of aqueous solutions of mixtures of potassium and sodium salts necessary to an intelligent handling of the more practical investigations under way. Practically all methods of extracting potash from natural sources involve the leaching by water of potassium salts with those of sodium and other bases from a less soluble residue. The separation and isolation of the potash from this aqueous solution is the most difficult and by far the most expensive operation in the vast



majority of the processes yet proposed, and careful work on this problem will contribute as much as any other one thing to the practicability of "making potash."

The fifth line of investigation has been the study of seaweeds and kelp. The kelps of the Pacific coast, both in extent and in composition, are far more important than those of any other known coast line. As a possible source of potash they are a most important and valuable national asset. The bureau has been fortunate in securing the services of Prof. George B. Rigg, of the University of Washington, Seattle; of Prof. Frank M. McFarland, Leland Stanford University; and Capt. W. C. Crandall, of the Marine Biological Association of San Diego, Cal. Through the courtesy of the association and of Director Wm. E. Ritter, of the La Jolla station, the services of the station boat were made available. About 100 square miles of kelp groves were surveyed; in Puget Sound, in the neighborhood of Monterey, and from Point Loma to Point Conception on the California coast. The composition of these kelps, and especially their potash content, has been determined. In addition, Prof. Wm. A. Setchell, of the University of California, and Dr. Carl L. Alsberg, of the Bureau of Plant Industry, have prepared expert reports on certain features of the kelp, and the United States Fish Commission has furnished some data obtained by the officers of the *Albatross* cruising in North Pacific waters. Mr. Wm. R. Maxon, of the United States National Museum, has identified some samples of kelp.

A sixth line of work has been an investigation of the phosphate resources of the country. Field studies have been made of the extent and characteristics of the deposits of phosphorites or rock phosphates in Tennessee, Kentucky, and Arkansas, following previous studies in Florida and in Utah, Idaho, and Wyoming. A study has also been made of the factory manipulation of the raw rock in the preparation of superphosphate, the production of sulphuric acid, etc., and the investigation is being continued to determine the distribution of the finished product, methods of use, and the use of ground raw rock and other phosphatic manures.

A seventh line of investigation has been to determine the resources of the country in nitrogen fertilizers. Attention has been given to the production of atmospheric products, cottonseed meal, slaughterhouse products, etc. But the main effort at the present time has been to determine, on the one hand, the location of deposits of nitrates, and, on the other hand, the possible production of ammonium salts from modern coke ovens and gas works.

#### PHOSPHATIC FERTILIZERS.

##### NATURAL RESOURCES.

The natural resources of the United States as regards phosphates are superior to those of any other nation. The material which alone commands attention is the natural phosphorite, "rock phosphate," natural or basic phosphate of lime, containing more or less carbonate of lime, and frequently incidental quantities of alumina, ferric oxide, and silica. Deposits of apatite occur in this country, and potentially there exists a large store of valuable material in the slags from iron furnaces. But neither apatite nor basic slag (at least from American sources) is of appreciable importance at

present or for the near future, since they can not compete with rock phosphate.

At the present time commercially available rock is expected to carry a percentage of phosphorus equivalent to 60 to 80 per cent tricalcium phosphate. Exceptionally, a product is mined running as high as 85 per cent tricalcium phosphate. Practically all of the high-grade material, that running 75 per cent or more tricalcium phosphate, is shipped abroad, the exportation for 1910 being approximately 1,083,037 tons, valued at \$8,234,276. The European markets generally demand a much higher grade of superphosphate or manufactured product than does the American. It is customary for them to use French and Belgian phosphates and the phosphates from Algeria and Tunis, all of which are low-grade rocks, from 55 to 65 per cent tricalcium phosphate. To bring their products up to higher grades they use the very high grade rock, carrying from 80 to 85 per cent tricalcium phosphate, coming from the Ocean Island of the South Pacific Ocean and Christmas Island and Ocean Island of the Indian Ocean and large quantities of American rock, chiefly from Florida. A relatively small quantity of Tennessee rock is also exported.

In America the fertilizer factories use rock grading from 58 to 72 per cent tricalcium phosphate. In recent years there has been a decided tendency to use higher grades, running from 68 per cent upward. This is due to the fact that the higher grade rock yields a more uniform and easily controlled product in the factory and a product of superior physical and mechanical properties important as affecting its shipping qualities.

To give an accurate estimate of the quantity of available rock phosphate in the United States is practically impossible, owing to the nature of the deposits in many areas and the yet limited extent of prospecting by competent scientific observers. It is certainly very large, well distributed both east and west, and, if carefully mined with due regard to elimination of wastage and utilization of lower grades, is sufficient for any imaginable demand of the future so far ahead that it may be characterized as practically inexhaustible.

The following figures are not intended as accurate estimates, but are regarded as ultra conservative. They will, however, suffice to show that there is no imminent prospect of a dearth of phosphatic material in this country:

Utah, Idaho, Wyoming, and Montana:		Tons.
High grade.....	2,500,000,000	
High-grade equivalent of low grade.....	6,667,000,000	
Tennessee, high-grade equivalent of all grades.....	160,000,000	
South Carolina, high-grade equivalent of all grades.....	3,000,000	
Arkansas, high-grade equivalent of all grades.....	20,000,000	
Florida, high-grade equivalent of all grades.....	150,000,000	
Florida, high-grade equivalent of wash heaps.....	16,000,000	

The present consumption in the United States is approximately 2,650,000 tons annually. Therefore, even assuming there are to be no new discoveries and that the average consumption during the life of the fields will be three times the present consumption, they would suffice for 1,200 years.

For convenience, the larger American phosphate deposits can be considered as the South Carolina, the Florida, the Tennessee-Arkansas-Kentucky, and the Utah-Wyoming-Montana-Idaho fields.

## THE SOUTH CAROLINA FIELDS.

These fields were the first to be exploited commercially. At present, mining there is falling off and the product is utilized mainly by local or near-by factories. Exportations from this field have practically ceased. The surface and easily accessible material has largely disappeared, mining operations are increasingly expensive, and the product is of medium or low grade and does not yield a superphosphate of as satisfactory quality as does the Florida or Tennessee rock, although mechanical condition and shipping qualities are excellent. Some of the South Carolina rock is, however, being manufactured by special methods into a very high grade or double superphosphate. Probably much rock remains in the South Carolina fields for future use.

## THE FLORIDA FIELDS.

The phosphate deposits of Florida are by far the most extensively mined in the world.

The rock as a whole is of such excellent quality and produces such uniformly high-grade acid phosphate that it is used (where conditions permit) in preference to any other phosphate, with the possible exceptions of that from the Ocean Islands and Christmas Island. There are two commercially important classes of phosphate rock in Florida—the hard-rock phosphate and the land-pebble phosphate.

The hard-rock fields extend north and south along the west coast of the peninsula for a distance of 100 miles. The present land-pebble phosphate regions lie south of the hard-rock fields, in Polk and Hillsboro Counties.

The methods of mining these two classes of phosphate rock differ considerably. In the hard-rock workings the material is either dug out or dredged. In the pebble deposits hydraulic mining is employed. Practically all of the hard-rock phosphate is shipped abroad and sold on a guaranty of 77 per cent tricalcium phosphate. The pebble phosphate is used both in this country and abroad, being sold on guaranties ranging from 60 to 75 per cent tricalcium phosphate.

In order to remove the impurities, the material which comes from the mines is subjected to a washing process, during which much valuable phosphate is washed out with the foreign material. It is estimated that the actual amount of phosphoric acid lost in preparing the rock for the market is nearly twice as great as the quantity saved.

In a bulletin on these deposits the Bureau of Soils suggests possible means of utilizing this waste material. It may profitably be applied to muck soils deficient in mineral phosphates. Methods for concentrating the phosphoric acid of these wastes are now being investigated.

The average cost of preparing hard-rock phosphate for the market is not less than \$3.50 per ton, while the finished pebble product costs about \$2 per ton.

Foreign corporations are large operators in Florida, but they do not control a major part of the output, and no individual foreign-controlled plant is as large as some of those operated by American capital. In the hard-rock fields there are about 20 companies engaged in mining operations. The total annual capacity of the operat-

ing plants is about 750,000 tons. In the pebble regions 15 companies are operating, with a combined capacity of over 1,600,000 tons.

Owing to various causes, the hard-rock industry is at rather a low ebb, many plants being entirely closed down. The pebble industry, however, continues to grow uninterruptedly.

#### THE UTAH, IDAHO, WYOMING, AND MONTANA FIELDS.

These deposits are of vast extent, far surpassing in tonnage those of South Carolina, Florida, Tennessee, and Arkansas combined. The latest estimate of the quantity of high-grade rock running 70 per cent or better in phosphate of lime is 2,500,000,000 tons, but there is fully four times as much material containing from 25 to 60 per cent phosphate of lime. It is highly important that mining operations should be so conducted that this vast quantity of lower grade rock will be available for future use.

A few thousand tons of the better grade of phosphate have been shipped to the Pacific coast and there made up into acid phosphate for the California trade, but the rock is mined to a very limited extent, since the demand for fertilizers in the West is not great and the fields are too far from the eastern market to make shipments of the phosphate profitable. Furthermore, title to many of the locations is in dispute and much of the land has been withdrawn from entry. This last fact is important, among other reasons, in that it offers an opportunity to insist upon the introduction of methods of mining which will minimize wastage. The United States Geological Survey has published two excellent reports on these fields, and the Bureau of Soils has issued a bulletin on the deposits, handling the subject from an agricultural and chemical standpoint.

#### THE TENNESSEE FIELDS.

The Tennessee phosphate fields are next in importance to those of Florida. They have frequently been described, but changing conditions, recent developments, and new methods of mining and handling the material make this field of special interest.

The brown-rock phosphate of Maury County, Tenn., contrary to popular opinion, is far from exhausted, and many deposits of high-grade rock in other counties have scarcely been touched. Deposits of high-grade rock are yet to be mined in Davidson, Hickman, Sumner, and Giles Counties. Modern mining methods now save much of the material which was formerly wasted. Pioneer methods of extracting the rock are still employed in the brown-rock regions, this practice being attended with much loss of good material.

Vast quantities of phosphatic limestone underlie and occur in the phosphate beds. This limestone frequently contains a high percentage of phosphoric acid, and steps should be taken to prevent its loss in mining the phosphate. In an appended report suggestions are given for utilizing this phosphatic limestone.

The cost of producing brown-rock phosphate for the market varies according to the nature and location of the deposit. Owing to the increased cost of labor and the installation of expensive plants, the cost of production is considerably above what it was in former years. A conservative average for mining and loading the rock

f. o. b. at the plant is \$2.50 per ton. There are fully 30 companies owning brown-rock property in Tennessee, but during the spring of 1911 only 15 of these were actually mining the phosphate. The combined capacity of the operating plants was 900,000 tons per year, but few were mining full time and some only intermittently. The marketed output of brown-rock phosphate for 1910, according to the figures of the United States Geological Survey, was 329,382 tons. This is a substantial gain over the production of the previous year. Mining operations in the brown-rock fields are not now as active as in former years. This is due to the increased cost of mining the rock and to the enormous development of the Florida phosphate fields, the rock from the latter region being usually preferred to the Tennessee rock by the manufacturers of acid phosphate.

Important areas containing blue-rock phosphate lie in Hickman, Lewis, and Maury Counties. Instead of removing the overburden, as is done in the case of the brown-rock phosphate, the blue rock is mined by drifting in on the vein or stratum and either blasting or drilling out the rock. This method of mining is rather expensive, but the blue rock does not have to be washed, and frequently drying is unnecessary. Owing to the fact that the beds vary both in thickness and quality and because some of the deposits occur at rather inaccessible points, the rock has not been mined to the same extent as the brown-rock phosphate. The marketed output for 1910 from the figures of the United States Geological Survey was 68,806 long tons. The cost of mining blue rock is approximately the same as that of mining brown phosphate, namely, \$2.50 per ton.

Both the brown and blue phosphate fields are rapidly passing into the hands of the large fertilizer corporations. These companies have installed expensive plants and are practicing modern mining methods. They consume much of the rock at their own fertilizer plants in the production of acid phosphate. The rock for this purpose contains from 65 to 72 per cent phosphate of lime and less than 6 per cent iron and alumina.

The white phosphate of Perry and Decatur Counties, Tenn., has not been mined since 1908. The rock occurs in pockets, and it is only by thorough prospecting that the extent of the deposits can be determined. Some of the rock is very rich, running as high as 85 per cent phosphate of lime.

During the spring of 1911 considerable prospecting was being carried on west of the Tennessee River, and plans were under way to resume mining operations on the east side of the river. The deposits are within 6 to 10 miles of the above-mentioned stream, which will no doubt be utilized in transporting the rock to the market.

#### THE ARKANSAS FIELDS.

The Arkansas phosphate deposits are not generally regarded as being of great economic importance, since, compared with the Florida and Tennessee deposits, the rock is rather low grade. The deposits are well situated, however, to supply the growing demand for fertilizers west of the Mississippi River. The developed region occurs in the northwestern part of Independence County, along Lafferty Creek, but the deposits extend over a considerable area in north-central Arkansas, the phosphate horizon being recognized in Stone, Izard, Searcy, Marion, Baxter, and Newton Counties.

The rock is of sedimentary character and occurs usually in two horizontal layers, one directly overlying the other. The first or upper layer is 3.5 to 6 feet thick and contains from 55 to 60 per cent phosphate of lime. Directly under this is another layer from 2 to 4 feet thick, closely resembling the upper stratum but of such low grade that it can not be shipped with profit. It is highly important, however, that mining operations should be so conducted that this material will be available for future use.

Only one company is operating in the Arkansas fields, but considerable phosphate property is owned both by individuals and corporations. These are only waiting for the market to become more active before starting mining operations. Fully 50,000 tons of rock have been mined in Independence County. The output is now shipped to Little Rock, Ark., and made into acid phosphate for the Arkansas and Texas fertilizer trade. The demand for fertilizers is constantly increasing in these States and the output from the Arkansas fields is growing to meet this demand.

#### THE KENTUCKY FIELDS.

Within the last few years considerable interest has been manifested in the phosphate deposits of northern Kentucky, but conflicting reports concerning the value of these fields have confused the prospective investor and discouraged mining development. Prospecting has been carried on intermittently in Fayette, Woodford, Scott, and Jessamine Counties, but no satisfactory, unbiased report on the deposits has yet been published.

In the vicinity of Midway, Woodford County, deposits of very high-grade material have been found, but the natural exposures are few, so thorough prospecting is required to determine the depth and lateral extent of the deposits. Samples have been taken from various places in Scott, Jessamine, Woodford, and Fayette Counties, and though examination of these fields has been necessarily superficial, sufficient data has been collected to show that phosphate occurs in paying quantities. The material occurs very much as does the brown-rock phosphate of Tennessee, which it resembles closely both in appearance and quality. The rock will have to be washed to free it from a matrix of foreign material, but this washing process is now practiced with great success in the brown-rock region of Tennessee.

Owing to the high price of land and the heretofore meager data regarding these deposits, the Kentucky phosphate fields have not as yet been developed. Plans are under way to start mining in the vicinity of Midway at an early date, and since these fields are well situated to supply the demand for fertilizers in the Middle West, the material will no doubt find a ready market.

#### NITROGEN FERTILIZERS.

##### NITRATE DEPOSITS.

In the exploration of the desert basins and neighboring arid areas attention has been directed especially to the discovering and location of deposits of nitrates. Many such deposits have been reported, but, on investigation, have proved to be of little or no economic im-

portance, either because of their limited extent, inaccessibility, or difficulty of working, and, generally, for all three of these reasons. Nevertheless, the interest in the possible location of nitrates is continually becoming greater. The bureau has, in confidence, been advised of several deposits of supposedly great importance and value. These are being examined as fast as circumstances will permit. Some of the reported finds have attracted considerable attention, as the deposits of Pena Blanca, near Mesquite, Dona Ana County, N. Mex.; Queen, Eddy County, N. Mex.; Briggs, Yavapai County, Ariz.; Gerlach, Washoe County, Nev.; Lovelocks, Humboldt County, Nev.; Grass Valley, Utah; Candelaria, Presidio County, Tex.; Ojinaga, Chihuahua, Mexico; Death Valley, Cal.; Blaine County, Idaho; Pocatello, Idaho, and Soda Springs, Idaho. As yet no deposit of known commercial importance has been exploited. But that such a deposit may be found is not impossible.

The origin of the nitrate deposits is not definitely known. Flood waters from higher levels, on evaporating, may be responsible for some of the reported finds of nitrates lying along the watercourses of arid areas. In the majority of cases the nitrates are the product of azoto-bacteria in the surface soils, which find especially favorable conditions for their activities in the alternations of temperature and moisture conditions at certain seasons. In other cases the nitrates are more or less obviously formed from the bacterial decomposition of such organic substances as bat guanos, common in caves, the nitrates remaining on the floor of the cave or seeping through the soil to appear elsewhere.

Nitrates are known to leach through the soil with exceptional readiness and are thus accumulated in the seepage waters. On evaporation at the surface of soils or porous rock masses, there is a surface deposition of soluble material and, when nitrates have been formed, these would tend to accumulate more rapidly, relatively, than other common mineral salts. Some such mechanism is probable, for it is common to find the surface crusts of nitrate deposits containing as much as 90 per cent or more of sodium or potassium nitrates or a mixture of these salts, while the material a short distance from the surface seldom contains more than a few per cent and commonly less than a fraction of 1 per cent of nitrates.

These facts, perfectly well known to soil experts, seem to be quite unknown to miners and prospectors generally who everywhere seem quite convinced that a surface deposit of nitrate necessarily indicates "richer" material underneath. Reports of large deposits are frequently made on very slim surface observations.

These natural deposits of "nitrates" are in no essentials different from the artificial niter beds, formerly used throughout the world generally, and yet extensively worked in India. The value of a natural deposit of nitrates is much exaggerated in the popular mind. Small beds are probably quite common in desert regions and will be frequently reported as these regions become better known and will generally be disappointments to the discoverers as having no commercial importance. Nevertheless, a large bed of nitrate, with water accessible, would have considerable commercial value. What that value would be is entirely problematical, for there is no American experience on which to base estimates. The labor and other economic as well as physical conditions are far different in Chile or wherever



such deposits are now worked. Moreover, the importance of a "mine" of nitrates lies mainly with the manufacturers of explosives.

The popular impression that the Chile saltpeter coming to the United States goes mainly into fertilizers is quite far from the truth. The proportion thus used has been estimated by different experts engaged in the trade at widely varying figures from 60 per cent down. From recent estimates of the Bureau of the Census, about a fifth of the importations goes to the fertilizer trade. Nitrates always will be in demand for certain special and highly intensive cultivations where very prompt and easily controlled results are demanded, as with greenhouse work, or with certain truck and fruit crops. For general farming other forms of nitrogen carriers seem to be finding more favor, and it is not probable that the location of even large deposits of nitrates would bring the selling price to a figure at which they could be freely used.

#### ORGANIC AND OTHER NITROGEN CARRIERS.

Enormous quantities of cottonseed meal are produced annually, but its value as a cattle feed is rapidly taking it out of the market as a nitrogen fertilizer. Tankage and slaughterhouse products and fish scrap are important, but far from sufficient resources. It is worth noting that large and potentially valuable amounts of fish scrap from the salmon and other canneries of Alaska and the Pacific slope are being almost entirely wasted, a state of affairs which should no longer be tolerated. The production of artificial "atmospheric" fertilizers like calcium cyanamid and basic calcium nitrate is of possible importance, but somewhat doubtful, because of dependence on much cheaper power sources than are now found in this country. The modern tendency to depend largely on the employment in the rotation of a leguminous crop accompanied by symbiotic bacterial activities seems to have a sound economic justification for general farming.

#### AMMONIUM SULPHATE.

There is a very important source of nitrogenous fertilizers in this country, which has not been adequately developed, and to which, therefore, the bureau is now giving attention, the production of ammonium salts from bituminous coal in the coke and gas ovens. Some ammonia is also produced in the preparation of "bone black" from bones and animal wastes. Ammonia can also be obtained from the gases of blast furnaces; this is done abroad, but not in the United States.

It has recently been stated by an eminent authority that the United States cokes nearly as much coal as do England and Germany together, but the United States does not produce one-sixth as much ammonia as do the foreign countries cited. On the average the coals of Pennsylvania, West Virginia, and Alabama can yield enough ammonia to furnish 1 per cent of their weight of coal as ammonium sulphate. The increasing demand for this salt, together with the increasing realization among American manufacturers that continued success requires the exploitation and utilization of all by-products, is bringing about the abandonment of the old and wasteful "beehive" coke oven and the substitution of modern "by-product"

ovens, with appropriate devices for collecting coal tars, ammonia, and other gaseous products useful for power development, heating, etc. So valuable are these by-products that it is currently reported one plant in Alabama actually returns to the coal shipper the coke produced and a royalty on the same for the privilege of obtaining the by-products.

From the amount of coal which is coked in the United States the annual production of ammonium sulphate should approximate 640,000 tons. Far less than this is actually produced, the figures for 1910 being 35,124 tons, valued at \$1,841,062. Since these figures were compiled, however, there has been an increase of about 25 per cent in the number of by-product ovens installed, and doubtless there is a corresponding increase in the ammonium sulphate produced. The amount imported for the fiscal year ending June 30, 1911, is 103,743 tons, valued at \$5,301,334. This importation is less than that for the year 1910.

It is impracticable to determine with any certainty the cost of production for ammonium sulphate, owing to the wide variations in the value of the other products obtained at the same time—namely, coke, gas, and tar. At present a fair average figure would be in the neighborhood of \$43 per ton. But considerable variations from this figure might apply to the various plants. The selling price of ammonium sulphate at the principal distributing points on the Atlantic seaboard is approximately \$3.10 per 100 pounds.

Several processes for producing ammonia synthetically from atmospheric nitrogen are now receiving more or less attention. It is reported that Frank and Caro have devised such a process, the success of which, however, depends upon cheap power. Similar remarks apply to the recently announced invention of Haber and Le Rossignol. In the United States, at least, no such process promises to have any commercial importance in the near future.

#### POTASH FERTILIZERS.

##### THE STASSFURT SALTS.

At the present time the United States, in common with the rest of the world, depends mainly on the deposits of soluble potash salts coming from Stassfurt, or more properly the Magdeburg-Halberstadt region of Germany. The United States takes nearly a fifth of the entire output of the mines and more than half of the amount exported from Germany. Salt mines containing workable amounts of potash are known elsewhere, as at Kalusz, in the Carpathian Mountains of Galicia, Hungary; on the right bank of the Rhine, in Belgium; at Elsass, Upper Alsatia; and a small deposit reported in Chile; but these are not worked to an extent which appreciably affects the world's supply, and none of their output comes to the United States. India still produces a considerable quantity of saltpeter or potassium nitrate ( $\text{KNO}_3$ ) from artificial "niter beds," and some of this material comes to the United States, but apparently in a somewhat sporadic manner. The amount of saltpeter coming into the United States in 1911, up to September 1, was 2,988 tons, valued at \$198,880. The major part of the saltpeter coming into the country goes into fireworks, brown powders, and similar explosives, and but little, comparatively, goes into fertilizers.

Practically, the potash fertilizers of the United States are prepared from the Stassfurt salts, of which the principal ones are:

*Kainite*.—A hydrated double salt of magnesium sulphate and potassium chloride,  $\text{MgSO}_4 \cdot \text{KCl} \cdot 3\text{H}_2\text{O}$ . Theoretically, this salt contains 18.9 per cent of potash,  $\text{K}_2\text{O}$ . The commercial product contains approximately 12.5 per cent potash. The imports of kainite during the fiscal year ended June 30, 1911, was 586,475 long tons. The value at Hamburg was approximately \$4 per long ton. On the Atlantic seaboard of the United States it costs, at present, approximately \$8.25 per short ton.

*Muriate of potash (or potassium chloride, KCl)*.—Theoretically, this salt contains 63.1 per cent potash,  $\text{K}_2\text{O}$ . The commercial product contains 42 to 62 per cent potash. The imports for the fiscal year ended June 30, 1911, were 192,505 long tons. The value at Hamburg was approximately \$33.50 per long ton. At the Atlantic seaports of the United States it costs, at present, approximately \$40 per short ton.

*Sulphate of potash (or potassium sulphate,  $\text{K}_2\text{SO}_4$ )*.—Theoretically, this salt contains 54.03 per cent potash,  $\text{K}_2\text{O}$ . The commercial product contains from 48 to 53 per cent potash. The imports for the fiscal year ended June 30, 1911, were 47,441 long tons. At Hamburg the value was about \$41 per long ton. At the Atlantic seaports of the United States it costs, at present, about \$46.50 per short ton.

*Manure salts*, or a mixture of the chlorides and sulphates of potassium, sodium, magnesium, and calcium, containing from 15 to 40 per cent potash according to grade. The imports for the fiscal year ended June 30, 1911, were 160,106 long tons. The value at Hamburg was about \$8 per long ton. It costs now at the American ports on the Atlantic about \$13.30 per short ton.

The imports of potassium salts going mainly into fertilizers during the fiscal year ended June 30, 1911, were as follows:

Salts.	Quantity	Value.
	<i>Pounds.</i>	
Muriate.....	431,215,560	\$6,440,576
Sulphate.....	106,268,142	1,952,368
Kainite.....	1,313,700,000	2,637,106
Manure salts.....	358,637,000	1,265,863
Nitrate.....	9,277,547	282,540
Total.....		12,587,462

The above values refer to port of shipment, and would be considerably augmented at the prevailing prices in the United States.

The following quotation is from a recent letter by an official of the German Kali Works:

In this connection we would say that we have recently been furnished with an official explanation of the expression "kainit," which is as follows:

"The ordinary commercial term 'kainit' is used not to denote one single mineral of definite composition, but to embrace a group of kainit salts—kainit, hart-salz, and sylvinit—as they occur naturally and by processes of transition in the potash deposits in Germany.

"The kainit seams, as they were formerly mined, are met with now only very occasionally throughout the many potash mines, so that the 'kainit' salts are now obtained from most of the mines in the form of hart-salz and sylvinit. The chemical composition of these varies not only according to the mines from which they are obtained, but also [they] fluctuate in composition from the same

mine according to the deposit and the method of mining. The above three salts are to outward appearance very difficult to distinguish, which greatly increases the difficulty of mining. For this reason the potash syndicate only guarantees the minimum amount of pure potash ( $K_2O$ ), which is the valuable ingredient so far as agricultural purposes are concerned. So far as the form in which the potash is present and the amount of other concomitant salts are concerned, no guaranty is made for the above reasons. In supplying kainit, i. e., the kainit salts at their full value, the minimum amount of 12.4 per cent potash ( $K_2O$ ) alone is guaranteed."

As you are doubtless aware some authorities formerly held that the potash in kainit was really in the form of sulphate. We are now officially advised that this is not so, but that the pure kainit has the same formula as was established many years ago by Rammelsberg; namely:



Since the potash in hartsalz and the potash in sylvinit are also in the form of chloride, there is no chemical reason for making any particular distinction between these materials when they are sold in the ground state in the market. Therefore, kainit, hartsalz, and sylvinit are now grouped together as distinguished from carnallit. In the American trade this distinction of carnallit is, of course, of no importance, as carnallit is never imported. The syndicate therefore divides the raw potash salts into two groups:

First. Carnallit salts.

Second. Noncarnallit salts (kainit, hartsalz, sylvinit).

For both groups only a minimum guaranty of potash is given, as the potash alone fixes the value and forms the basis for the calculation of prices. No account is taken of the other constituents, which are only of a secondary importance from a manurial standpoint.

From the above you will note that there is a marked similarity between the system of classification of American railways and that of the classification of potash salts. In the railway classification "pigs is pigs" and in the potash classification "kainit is kainit."

#### MINOR SOURCES.

Enormous stores of potassium exist in the United States, and now that public attention has been drawn to the matter it is probable that some of them, at least, will soon be utilized on a commercial scale. Such materials as wool washings have long been known to be an available source of potash. The vinasses from American sugar mills are quite large in the aggregate, though no reliable estimate has yet been made. Frequently they run quite high in potash as well as in other substances having a commercial value, at least, for local consumption. Much less important, but still far from negligible, are the pomaces from wine presses.

The amount of sawdust produced annually by the cutting of our forests amounts to about 5,850,000 tons, containing approximately 5,200 tons of potassium carbonate. At this rate the annual sawdust production should, as a source of potash, be worth about \$250,000. This is probably a rather liberal estimate, and, considering the wide distribution of material, the location and character of the product, sawdust seems to be a very minor possible source of potash.

Hardwood ashes from Canada come into this country to a small extent. Late figures are not available, but for the fiscal year ended June 30, 1910, the importation was 5,020 tons, valued at \$60,220. The State experiment stations value the material at \$9 to \$12 per ton, according to analysis. The average price at present is about \$12 per ton. These ashes are sold as fertilizers to some extent on the New England market. An appreciable, though not accurately known, portion is taken by soap makers, glass factories, and other manufacturing interests. The smoke from wood fires contains carbonates

and sometimes other salts of potassium, and the smoke and fumes from various industrial operations, as, for instance, cement works, are known to contain frequently some soluble potash salts, usually the chlorides. It is reported that in Russia the stalks of sunflowers grown on otherwise waste land are used as a source of potash. But even were it practicable to collect potash from such sources it is very doubtful if it would prove a sufficient and reliable supply for fertilizer needs.

#### DESERT BASINS.

The popular mind turns to the expectation of a "mine" of potash or to a large deposit of it, and naturally looks for either in the more arid sections of our country. That surface or buried deposits of salts with segregated layers of potash salts might exist in such regions has long been a cherished hope of the scientist, although the advance of knowledge concerning these regions has rather diminished than increased this hope. Color has been lent to popular belief in the presence of potash salts in arid regions by the relatively high proportion of potash to other salts sometimes observed in "alkali"—the accumulation of soluble salts at or near the surface of the soil. Such occurrences are, however, elusive, rendered more so frequently by the manner of stating the analytical data. Some hundreds of analyses of alkali soils and crusts made by the Bureau of Soils have been inspected, and all the cases showing more than 0.5 per cent potash in the soil are given in Appendix F.

Up to the present time no surface deposits containing commercial quantities of potash salts are known in the desert basins. From the information which has now been gathered, it is improbable that there are any such deposits. But this is not certain, and there is a chance that segregated beds of potash salts may occur in some of the buried salt deposits. Apparently the best prospects are in the Humboldt Basin in Nevada, where the Geological Survey is now drilling, with lesser prospects in the Surprise, Warner, and Christmas Valleys of Oregon, and the Salton Basin of California. An enormous evaporation must have taken place to deposit any considerable quantity of potash from such natural waters as are now known entering the desert basins, an evaporation possibly greater than there is reason to believe actually took place. As there is no evidence that high concentration of potash existed in the earlier drainage, or that any selective action ever took place, the existence of potash beds in the arid regions of this country can not be predicted with any confidence. On the other hand, the existing data do not justify a positive opinion to the contrary, and an examination of the desert basins is far more than justified, especially as other valuable substances, such as saltpeter, niter, alunite, phosphorites, borates, etc., are thus being brought to light.

The soluble salts of potassium are usually classed with the so-called "salines," including such easily soluble salts as sodium chloride or common salt, sodium carbonate or "soda," sodium sulphate or Glauber's salt, and the like. All known natural beds of such bodies have resulted by concentration of water solution. Whatever may have been the ultimate origin of the materials, the immediate source is nearly always the small quantities of salts extracted from exposed rocks by running or percolating waters and carried in the drainage.

All ground and surface waters carry varying quantities, usually small, of dissolved salts, and upon evaporation these salts are left behind in the final resting place of the waters. The ocean is the great depository of saline materials, and its high salinity has been acquired thus. But there are areas the drainage waters of which evaporate without reaching the ocean at all. Such are the Great Basin of Nevada and Utah and the smaller basins which cluster on its borders. Since these received their present topography their waters have not had egress to the sea, and such salts as these waters may have carried are still within the basins and represented by salty lakes or beds of saline material.

At present the influx of salines to these basins is not large. Rainfall is low and there is little opportunity either for the chemical decay which would free soluble salts from the rocks and for which water is necessary, or for the extraction and carriage of such salts as may have been freed. But this condition of low rainfall is probably of no great antiquity. Old beaches, river deltas, terrace lines, etc., indicate that at a time geologically recent, though historically remote, the undrained basins of the Western States were nearly all filled with large and persistent lakes. There is evidence that this filling was several times repeated, and there is every reason to believe that the filling or fillings corresponded to periods of greater rainfall or lower evaporation, or both, and that they may be correlated with the successive periods of advance of the North American ice sheet, which periods are known collectively as the Glacial Epoch. Even these periods were not sufficiently rainy to cause the Great Basin to overflow, but the country was probably fairly well watered, and the supply of saline materials to the central lakes was much larger than at present. These salines must still be in the basins, either on the surface or as buried beds.

Therefore, any potassium salts which have been freed from the rocks of any undrained basin are still within it, though it is always possible that they are so mixed with other salts or with alluvial sand or clay as to render their commercial utilization difficult or impossible. No segregated deposit of potassium salts has ever been discovered in the undrained basins, but explorations have been meager and directed to other ends, and this negative result is by no means conclusive. Indeed, segregated deposits of potassium salts are known in a very few localities, notably at Stassfurt, Germany. They have there resulted from the concentration of sea water. The salines of our undrained basins, with the possible exception of the Salton Basin, are altogether of continental origin.

Being continental, the salines of any basin have been derived from the rocks immediately surrounding that basin. In general, rocks of marine sedimentary origin yield marine salts with sodium chloride greatly predominant; fresh water sedimentaries yield only small quantities of any salts. Igneous rocks yield salts determined by the decay of the particular rock-forming minerals which happen to be present. From these several classes of rocks the salts are mainly salts of sodium. Very little or no potassium can be expected from sedimentary rocks of any kind or from the usual igneous rocks in which the sodium feldspars predominate. The only common rocks likely to give any appreciable quantity of potassium to the drainage are those in which the potassium feldspars (microcline and ortho-

clase) are common. Practically, this means certain acidic lavas and granite.

When a drainage water is evaporated the dissolved constituents separate as solids, certain solids being precipitated before others in perfectly definite order, depending upon the nature and composition of the mixture of constituents. The order of precipitation of the several salts from sea water is now fairly well known and in many cases at least the variation from this order which will take place with any given solution, such as lake water, can be fairly well predicted. In general, calcium carbonate and the sulphates of lime, anhydrite and gypsum, will be the first minerals to form. Sodium chloride is the next salt to appear as a solid, and in the case of sea water and many lake waters will continue to separate mixed with the salts of magnesium and potassium, until desiccation is complete. Magnesium and potassium salts tend to segregate in the mother liquors of the brines. Consequently, the potassium, in the form of various salts and mixed with relatively larger or smaller proportions of magnesium, sodium, and lime salts, is usually found in the upper (but not necessarily the top) layers of a salt deposit. Of course a succeeding influx of water and its desiccation may not only impose a second succession of salt layers, but may more or less completely confuse the first layers. In fact, it is extremely difficult if not impossible to predict just where to look for potassium in a salt deposit.

It should be noted also that the possible position of potassium deposits is by no means confined to the present surface of the basins. These basins usually contain considerable thickness of recent alluvial material, and it is not improbable that this material may cover or inclose salt beds laid down during earlier periods. Between the past periods of greater rainfall and of lake expansion there intervened probably periods of aridity. The aridity may have been even greater than that of the present. These arid periods would correspond to the periods of glacial recession known to have alternated with the successive periods of advance. If this be so, and there is good reason for it, the great lakes of the rainy periods must have gone nearly or quite to dryness during the dry periods and the saline materials brought in and accumulated during the expansion must have been laid down as salt beds during the subsequent recession. Upon a return to more humid conditions such salt beds might be easily covered by clay or other alluvium and thus preserved more or less from re-solution. This process of "freshening by desiccation," according to Russell and Gilbert, explains the freshness of some of the lakes which now dot the Great Basin region, and its reality in some cases at least can scarcely be questioned. Like the surface beds, such buried beds would be mainly salts of sodium, but there is always a chance that potassium might be associated therewith. The occurrence and composition of saline springs, well waters, or salt seeps as indications of buried salt beds and the association of potassium salts therewith is of importance, as is also the recent geology of the particular area.

*The Lahontan Basin.*—The core of the Great Basin itself, in the central and northwestern part of Nevada, was, during the Quaternary period of greatest lake expansion, a single great lake, the

history of which has been admirably studied by Russell,<sup>1</sup> who gave it the name of Lake Lahontan. The basin which it filled is nearly a unit, the divides which separate its various parts being either low or discontinuous. The old lake is now represented by a few insignificant remnants—Lakes Pyramid, Winnemucca, Walker, etc.—and by a number of sinks, playas, and saline marshes. The salines now present on its surface or in the tiny lakes which dot it are trifling in amount and certainly far less than the salt which can reasonably be assumed to have been present in the waters of the larger lake. This fact was recognized by Russell, who accounted for the absence of the hypothetical salt by the assumption of burial under alluvial coverings. Succeeding investigation has strengthened this conclusion, and it may be considered reasonably certain that salt beds of some sort underlie the present floor. There is no assurance, however, that these beds are in segregated form.

Still less can it be concluded that the buried beds contain any notable proportion of potassium salts. The rocks of the basin and its drainage area are largely igneous but usually low in potassium. The salts of the early lake were probably largely sodium salts. But Lahontan was a large lake, and its evaporation should have left a large quantity of saline material and a not insignificant quantity of potassium. There are no surface indications either for or against the occurrence of potassium, and the matter can be settled only by boring, as the Geological Survey is now doing in this area.

*The Bonneville Basin.*—East of the Lahontan Basin, in northwestern Utah and extending somewhat over the eastern boundary of Nevada, is another somewhat smaller basin, also a topographic unit and also once occupied by a great Quaternary lake known as Lake Bonneville, which has been thoroughly studied by Gilbert.<sup>2</sup> This lake has not entirely dried, its remnant being the Great Salt Lake. The Bonneville Basin differs from that of Lahontan, not only in area, but in being set mainly in Paleozoic sediments instead of in rocks of igneous origin. It is to be expected, therefore, that its salines are largely sodium chloride, with much smaller amounts of other salts. Apparently this is the case. There is, approximately, 0.9 per cent potassium (K) in the lake at the present time, but this is too small to be of commercial importance and there is no satisfactory signs of buried deposits. It is not possible to say definitely that the lake has never gone entirely to dryness, but it is very probable that it has not. The topography of the basin is such that very intense aridity would be required to entirely desiccate it, and if this did happen little insoluble alluvium would reach the final bottom and the salts there laid down would scarcely be protected from later solution. Neither the probable geological history of the basin nor the character of the rocks in which it lies offers any great promise of the presence of potassium.

*The smaller basins of southern and central California and southern Nevada.*—South and southwest of Lahontan the country is likewise lacking in seaward drainage and the early lake periods are likewise in evidence, but there is a sharp difference in topography. Instead of falling into one or more great basins the area is cut by high and

<sup>1</sup> Monograph XI, U. S. Geological Survey, 1885.

<sup>2</sup> Monograph I, U. S. Geological Survey, 1890.



continuous mountains into a number of small basins, each of which has its individual characteristics and history. It is these basins which constitute the present Mojave Desert and the Death, Armagosa, Saline, and similar valleys to the north and northeast. These basins are so imperfectly known that few reliable conclusions are possible. Their saline contents are apparently rather varied, but, so far as known, are exclusively salts of sodium. There are no known evidences of the occurrence of potassium and the known rocks are mainly sedimentaries or igneous rocks low in potassium. The basement granites of the Sierra Nevada are exposed in places in the western part of the area, especially toward the south, but these exposures have probably been uncovered only by recent erosion and are now much larger than in the recent past. On the whole, the evidence appears unfavorable to the occurrence of important potassium deposits, but it is insufficient and there is need for more detailed information concerning many of the units of the area. Buried salines are reported as existing in a few places, but their nature and associations are almost entirely unknown.

On the extreme western border lies Owens Lake. This lake is very saline and contains about 0.35 per cent potassium (K). It is possible that methods may be devised for the commercial extraction of this potassium, and investigations to this end are now under way in the laboratories. The general examination of the salines of this basin is also under way.

*The Salton Basin.*—The great depression of southwestern California, known as the Colorado Desert and now partially occupied by the Salton Sea, differs markedly from the basins just discussed in that it is separated from the sea by a low and recent divide and in that its recent history has been severely modified by the Colorado River. The Salton depression is apparently a northward extension of the rift which forms the Gulf of California, and seems to have been cut off from this gulf by the delta which the Colorado River has built across it from its debouchment on the eastern shore. The river has probably flowed alternately to the southward into the gulf as at present, and to the northward into the depression as it did for a time following the catastrophe of 1905. Continued flow into the depression would mean complete filling and flowing over the low divide to the south, and the recent beach line which surrounds the basin at about 40 feet above sea level was doubtless cut during the latest of these fillings.

On the return of the river to its gulfward channel the great lake which had cut this beach line dried up and its saline contents were deposited in the so-called Salton Sink. Before the recent flooding the saline beds so produced were exploited for common salt, and their nature and composition is pretty well known. They were mainly sodium chloride, with small quantities of sodium sulphate and of magnesium salts. There were only very small traces of potassium. Any salt beds deposited by earlier similar fillings by the river since the shutting out of the sea, and later buried by alluvium, would doubtless be similar to this last one, and probably but little potassium would be therein.

The case of an earlier marine filling is somewhat different. It is possible, though not certain, that the delta of the Colorado was built across the gulf while it was occupied by the sea, and that an

arm of the ocean was thus gradually cut off from its seaward connection and gradually evaporated after this severance was effected. Did this occur, the conditions would approach those which existed at Stassfurt, and it is possible that similar segregated potassium beds might have been deposited. But the existence of the cut-off sea arm is uncertain, and, at the best, its volume was relatively small, and its possible saline deposition far smaller than at Stassfurt. The solution of this problem may require deep borings into the basin. A careful examination of certain features of the regional geology, notably the recent uplifted hills along the northern border, is now in progress and is expected to furnish important information bearing on the problem.

*The lake basins of southeastern Oregon and northeastern California.*—North and northwest of the Lahontan Basin lies a region which greatly resembles in topography the region to the south and southeast already discussed. However, a greater rainfall and a steeper relief have prevented the entire desiccation of most of the basins, and they are now occupied by shallow lakes. This region has been investigated and the nature and quantity of salines have been examined in detail. Some of the lakes are moderately saline, but none are strongly so, and the salts are mainly salts of sodium. The analyses of samples collected in this region have not yet been completed, and it is therefore impossible to state in detail the percentages of potassium in the various lakes. These percentages are probably low, but were they reasonably high the region would still have little commercial importance because of the small depth of the lakes (2 to 15 feet) and the small quantity of water and dissolved salt they contain.

There is little evidence of buried salines in most of the desert basins, but there is a possibility of their occurrence in the Surprise Valley in Modoc County, Cal., and in the Warner and Christmas Valleys in Lake County, Oreg. The last valley contains no large lakes. In all three of these valleys there are salt seeps, and salt waters are occasionally encountered in wells. Furthermore, each valley was once the site of a large lake, and the saline contents of these lakes have disappeared. In the Surprise Valley there is an unconfirmed but probably trustworthy report of the findings of sand strata cemented with salt. The region as a whole is one of recent basalt, carrying practically no potassium, and the "islands" of older acidic lavas which penetrate the basalt cover are few and small. Of the three valleys mentioned, the Surprise Valley seems to be the most promising. Its walls carry abundant exposures of what seem to be rhyolitic tuffs, probably fairly high in potassium, and which may have contributed largely to the valley salines. The chances for the occurrence of segregated potassium appear to warrant further exploration.

*The basins of New Mexico.*—Of the several detached undrained basins in New Mexico the largest—the Otero—has been examined in considerable detail. The surrounding rocks are nearly all sedimentaries, and such few igneous exposures as exist are prevailingly low in potassium. Only traces of potassium were found in the drainage waters or in the brines or salt beds of the central playas, and the absence of potassium from the surface may be considered practically certain. Buried salines are possible, but not probable, and, even if

they exist, there is no likelihood of their carrying potassium in commercially important quantities.

The other and smaller basins of New Mexico are similar to the Otero in surrounding rock and in general features, and probably equally barren in potassium.

*The small basins bordering the arid area.*—In addition to the undrained basins of the above groups there are (mainly just beyond the seaward borders of these groups) a few other areas now undrained. Examples of these are Goose Lake of northern California, Harney and Malheur Lakes of east-central Oregon, the many "dry valleys", of the Colorado River drainage area in Arizona and southern Utah, etc. Almost without exception these basins are separated from some seaward drainage channel only by low divides over which discharge actually took place in very recent geologic times. These basins are really parts of the drainage areas of the various rivers to which they are contiguous and have been separated therefrom simply by the great aridity of the present period or by some geologic accident, as a lava flow in the case of Harney and Malheur Lakes. Since these basins have recently discharged both water and salt into the ocean, they can not have retained any important quantity of salines, and in so far as the present inquiry is concerned, their importance vanishes.

#### BRINES, WELLS, AND SALT DEPOSITS.

Many, if not all, of the brines from American wells carry some potash salts, though generally in small proportion to the sodium chloride and other salts. This fact may be important for two reasons. In crystallizing out the sodium chloride by evaporating the water the potassium concentrates in the mother liquor or "bittern," and there is a possibility that the bitterns might prove available sources of potash; and, again, the presence of potassium salts in a brine may prove a valuable guide as to the desirability of exploring a locality for beds of segregated salts. It happens that the Geological Survey is at this time especially interested in the composition of brines for other reasons. This bureau is therefore cooperating with the survey in collecting samples of brines and bitterns under standard conditions. Between 300 and 400 such samples have thus been collected from the States of New York, Ohio, Pennsylvania, West Virginia, Kansas, and California, and these are being analyzed in this bureau, with a view to having on record the most comprehensive, complete, and carefully obtained data regarding salines ever brought together. Analyses of this character are very exacting and time consuming, but a number of these analyses have now been made, including data for bitterns, from upward of 50 wells. In all cases the content of potassium is quite small, in no case exceeding 0.2 per cent and generally much lower. Even though the aggregate amount of potassium obtainable from such brines be large there is no promise at present that they would have much economic significance. As pointed out above, the separation of potassium salts from a solution containing sodium salts is not an easy one from a commercial point of view. Possibly a low-grade manure salt might be produced commercially from some American brines, but it is very doubtful if the product would pay for the cost of evaporation and other necessary manipulations.

The results thus far obtained indicate, however, that further exploration of some of our deposits is desirable with a view to locating segregated beds of potash salts. Very little precise knowledge is extant concerning these deposits. Usually the prospectors, either of wells or of rock-salt mines, have been content when they have reached paying layers of sodium chloride, and little or no effort has been made to explore further. It would probably be wise to make deeper borings, as, for instance, in some of the New York deposits, to determine whether or not beds of potash salts are below the present workings of sodium chloride.

#### POTASH SILICATES.

There are in this country many and large deposits of the potash feldspars, orthoclase and microcline, some of them carrying as high as 16 per cent potassium. These feldspars are frequently a prominent constituent of enormous occurrences of granite. Glauconite, the characteristic mineral of the greensand marls, is a hydrous silicate of iron and potassium occurring in large deposits in New Jersey and in the South Atlantic and Gulf States. Leucite, a potassium aluminosilicate found in lava flows; nepheline, muscovite—the common potash mica—and other minerals increase the total of existing potash stores to a figure of amazing proportions. It is not surprising, therefore, that methods to abstract potassium from silicate rock-forming minerals has long attracted the attention of chemists and inventors. At the present time efforts in this direction are particularly active. In Appendix G is given a list of some of the typical patents, but other inventors have, in confidence, given to the bureau the details of their methods.

The natural potassium silicates, when finely ground so as to present a large surface to the action of water, dissolve to a certain extent and are completely hydrolized, yielding very dilute solutions of potash. This is, in fact, the mechanism by which plants naturally obtain their needed potash, since most soils contain small fragments of orthoclase or microcline and other silicates which yield potash to the soil solution. In general, solution increases with temperature and, so far as known heretofore, hydrolysis increases with rise in temperature. However, from experiments made with glass some years ago it seemed probable that heating feldspars and similar minerals with water to a moderately high temperature, 500° C. to 600° C. (and necessarily under high pressure), would result in more or less complete solution. The experiment was tried with a number of feldspars, glauconite, etc., and it was found that high temperature and pressure actually seemed to depress the solvent action of pure water on the minerals tried.

Besides water itself, various aqueous solutions and salt and salt mixtures have been tried in the hope of extracting potash from the silicate rocks. The great majority of these processes are, practically, modifications of the well-known and generally practiced laboratory method of J. Lawrence Smith, the essential feature of which is to fuse the silicate with calcium chloride. As an analytical procedure in the laboratory the method is quite satisfactory. Undoubtedly, potash can be obtained in this way, but not necessarily on a commercial scale. The same statement holds for some of the other

procedures proposed. But the majority of the methods that have been put forward for extracting potash from rocks are obviously absurd. Without at this time going into a critique of all the various methods proposed it is well to call attention to certain definite conclusions coming from a consideration of the various methods.

Nearly all of the methods proposed in their final stages involve the separation of a potassium salt from salts of sodium and other bases. This, as already pointed out, is not an easy thing to accomplish on a commercial scale, although there are reasons for thinking that it may be done under certain special conditions. Secondly, practically all these methods require the evaporation of large volumes of water, a very expensive procedure. Water has a relatively high specific heat; that is, it requires more heat to raise a given mass of water 1 degree in temperature than is required for an equal mass of any other substance occurring in nature. Therefore, unless large supplies of very cheap fuel are available, an industrial operation requiring the evaporation of large volumes of water is objectionable. Spontaneous evaporation, especially in arid regions, is frequently urged as a merit of certain proposed schemes. These are to be regarded, however, with extreme caution, for spontaneous evaporation implies a large area of shallow containers, and, generally, even if cheap land be available, the other costs of installation and maintenance are prohibitive.

It seems to have been clearly demonstrated that no method of extracting potash from silicates has any commercial possibility if dependent only on the sale of the potash produced. By-products must have a market sufficient to pay for the cost of the raw materials, and sometimes more. Obviously, the raw materials must be obtainable cheaply and from a steady source of supply. So far as is yet known, no process has met these conditions except on a rather small scale. For instance, one of the patented processes now before the public employs ground orthoclase and acid sodium sulphate, and produces a pulverulent soda feldspar-albite, a very pure sodium sulphate, and hydrochloric acid, besides yielding practically all the potash in the form of chloride. The albite seems well adapted for glazes, certain types of tiles, etc., but has apparently a limited and uncertain market. There is a steady but very limited demand for the pure sodium sulphate, and there is available a small and steady supply of cheap acid sodium sulphate as a by-product from another industrial operation. Consequently, potash can possibly be extracted from orthoclase by this method at a profit. But the amount that can be produced is limited on the one hand by the cheap acid sodium sulphate available, and on the other by the market for the pure sodium sulphate produced, and there is no immediate prospect that the available supply of potash in this country is to be greatly augmented from this source.

It is well in this connection to warn the general public, which seems peculiarly prone to listen to promoters with "chemical" or "scientific" propositions. It is little short of folly to invest in such schemes before getting the advice of a competent and disinterested chemist or chemical engineer. Especially is this the case with the so-called secret processes. It may be laid down as a general rule, with practically no exceptions, that secret processes are not for the layman or small investor. If a secret process has any real merit it is too valuable to already existing interests to be allowed to get away from them.

Every inventor knows this, or he will soon be made to realize it, if he has anything worth securing.

For the nonexpert small investor to put his money into such schemes, without having secured competent expert advice from a reputable, disinterested source, is to indulge in wild and reprehensible gambling.

#### ALUNITE.

Although the extraction of potash from silicate rocks, commercially, does not appear to be a promise of the near future, there is one mineral which offers interesting possibilities, namely, the basic alumino-potassic-sulphate, alunite. At Tolfa, near Rome, Italy, where large deposits of the mineral occur in massive form, it has long been used as a source of alum. The material is roasted and then leached, and the alum crystallized from the leachings on evaporation. The product obtained at Tolfa frequently has a reddish color, due to iron, and this reddish alum appears to be well known to the trade under the name of Roman alum. Large deposits of massive alunite are said to exist in Japan, but how far they are utilized has not been ascertained. Numerous deposits of alunite have been reported in the United States, the major deposits so far examined being at Rosita Hills, Custer County, and in the Rico Mountains, Colo.; National Belle Mine, near Silverton, Colo.; and at Cripple Creek, Colo.; near Humboldt House, Nev.; Alunite, Las Vegas, Nev.; in several localities in Arizona; Goldfield, Nev.; at Tres Cerritos, Mariposa County, Cal.; and a large deposit of the massive mineral about 8 miles southwest of Marysville, Utah. It is reported that alunite is the main constituent making up the mass of Calico Peak, Colo. Hitherto alunite deposits in this country have been regarded with interest mainly because of their well-known association with gold ores.

Experiments with alunite show that with a moderate heating, followed by lixiviation, the product obtained is ordinary potash alum. With a somewhat higher and long continued heating sulphur trioxide ( $\text{SO}_2$ ) is evolved, which can be conducted into water, thus yielding sulphuric acid ( $\text{SO}_2 + \text{H}_2\text{O} = \text{H}_2\text{SO}_4$ ). Lixiviation of the roasted mass yields a very pure solution of potassium sulphate. The leached residue seems very well adapted to compete with natural bauxite. Efficiency runs in the laboratory, which could probably be much bettered in practice, yielded, in dry crystals of potassium sulphate, 83 per cent of the potash in the raw mineral. Further investigations of the possibilities of the mineral are now in progress. Regarding the commercial exploitation of the Colorado deposits little can yet be said, and further examination in field and laboratory are highly desirable. Recent reports from competent mining engineers indicate that the deposits at Goldfield are more extensive than formerly supposed. That they may have a value as a source of potash is by no means improbable. If the preliminary reports concerning the Utah deposits are confirmed these seem to have the greatest interest, not only on account of their character which makes them better adapted to manufacturing than the other deposits, but because of their position near large phosphate fields. Sulphuric acid, very easily obtained from the roasting of alunite, could be advantageously used in producing superphosphate; that is, two of the most valuable of

fertilizer salts, potassium sulphate and superphosphate (monocalcium phosphate) can be made at the same time, with practically but one by-product, artificial bauxite, for which there should be a good market. Experiments now in progress in roasting mixtures of alunite and rock phosphate promise some interesting results of possible economic importance.

#### THE MANUFACTURE OF FERTILIZERS AT SALT LAKE.

The eastern shore of the Great Salt Lake is rapidly becoming a great railroad center, and is potentially one of the most important distributing points in the country. It is in close proximity to the largest high-grade deposits of rock phosphate in the world, and to the best deposits of alunite in this country. It is better situated than any other point to utilize any valuable deposits which the desert may yield, such, for instance, as nitrates. In the smelter fumes at Garfield and the other neighboring smelters it has at its door a vast source of material well suited to the production of the sulphuric acid needed in the manufacture of superphosphate—a material (the smelter fumes) which, by the way, has become a great public nuisance, and must be disposed of in some way. All the conditions point to Salt Lake City and Ogden as the great fertilizer manufacturing centers of the future. Hitherto the smelter interests have objected to converting their fumes into sulphuric acid on the twofold ground that the people in their localities do not use fertilizers, and if they did use them, the production of acid would be far greater than the demand. It is doubtless true that attempts in this direction would at first lead to financial losses of magnitude. But there is good reason to believe that if the smelters of Utah were to follow the suggestion here offered they could put high-grade fertilizers on the market so cheaply that in a very few years the agricultural interests of the surrounding territory would use the entire output, and an important industry would be developed. Obviously, it would be a public work of the first national importance to develop such an industrial center midway in the territory between the Mississippi River and the Pacific coast.

#### THE PACIFIC KELP GROVES.

The most promising source of potash in the United States is the beds of seaweed or kelp groves along the Pacific coast. Attention has been called to the value of the giant kelps from time to time, notably by Mr. David M. Balch, of Coronado Beach, Cal., who has given much time and energy to their investigation. The kelp groves are frequently very extensive. Dall reported in 1875 that there was a bed of bull kelp 25 square miles in extent northeast of St. Georges Island, Bering Sea. Setchell and Gardner have reported that *Nereocystis* is plentiful from the Shumagin Islands, Alaska, to Santa Barbara Channel, Cal. By far the most extensive beds lie along the southern coast from Point Sur to Magdalena Bay.

That kelps have a value as a fertilizer has long been known. This has been attributed in part to their content of potash, in part to the fact that they decompose very readily and rapidly after being cut or broken from their anchorage, in part to their small content of iodine, and in part to their phosphate content. To a very limited

extent and in a wholly occasional way, kelps have been used thus along the Pacific coast. They have long and quite extensively been used along the New England coast, where the torn kelp is thrown up on the shore in the fall by the heavy seas then prevailing and at a season following the harvest when labor can be spared for the gathering. In fact, kelp gathering is made, in many localities, a gala occasion. In England, Scotland, Ireland, the Channel Islands, Norway, and the coast of Brittany kelp is still gathered, more or less extensively and spread as a manure. Interest in this material as a manure has recently increased in England, and the Board of Agriculture and Fisheries has issued a circular (Leaflet No. 254) concerning the use and value of British kelps for different types of soil and different classes of crop plants.

For many years the European kelps were gathered as a source of iodine and the shore rights for gathering them were at one time very valuable. Gradually it became the custom to burn the kelp; the ashes were collected from place to place by vessels making more or less regular collections, brought to Glasgow and there leached for their iodine. The residue containing notable quantities of potash and some phosphates were sometimes sold as fertilizers, sometimes simply discarded as waste of too little value to pay for the handling. But the world's supply of iodine was controlled from Glasgow. Later, when this supply was obtained from the mother liquors in the refining of Chile saltpeter, the control of the output remained in Glasgow, although the extraction of iodine from kelp was practically abandoned. Control of the production and distribution of iodine yet remains in Glasgow, except that Japan supplies its own needs from kelp, the industry having been revived in that country on the breaking out of the war with Russia.

In Japan some varieties are also used for food products, known as kobu, konbu, or kombu, a dried material forming the basis of various dishes; still other food preparations are known as "nori" kanten, agar agar, etc., and considerable quantities are gathered, baled, and shipped to China, forming the only supply of salt for some of the interior Provinces of that country. On the Pacific coast of the United States kelp is the basis of several small industries, the annual value of which is probably only a few thousand dollars. Certain varieties are made into curios and souvenirs. The most notable of these minor industries is the invention of Prof. Frye, of the University of Washington, in which the salts are leached from the bulbs and larger stems of the "bull kelp" of Puget Sound, and the residue is seeped in sugar sirup with various added flavors. A sort of conserve, much resembling candied citron, is obtained, which, for obvious reasons, has been named "seatron."

The kelps of the Pacific coast of the United States are essentially different in certain respects from the Atlantic kelps and apparently from those of Japan. They yield a much higher percentage of potash (five or six times as much as the Atlantic kelps), but have a much lower percentage of iodine. Analyses have been made of oven-dried samples of the principal varieties of kelps from Puget Sound, the coast near Monterey, and the coast near San Diego. The average of seven samples of the principal varieties shows the Puget Sound kelps to contain 30 per cent potassium chloride, and 0.16 per cent iodine; the average of the six samples from Monterey shows 31



per cent potassium chloride and 0.18 per cent iodine; and the average of 30 samples from San Diego shows 23 per cent potassium chloride and 0.29 per cent iodine. It is doubtful, however, if there is actually any essential difference in the yield of potash from the northern and southern kelps. It does seem to be the case, contrary to popular belief, that the southern kelps are richer in iodine than the northern kelps.

The principal kelp of the Puget Sound is the *Nereocystis luetkeana*, commonly known as bladder kelp or bull kelp, and is probably the only one which will justify harvesting. Rigg found specimens 70 feet long, though the average would probably fall considerably short of this. The average content of potassium chloride seems to be between 30 and 35 per cent of the dry weight and the iodine content about 0.15 per cent. Other varieties of kelp occur, the next most important one being *Macrocystis*, attaining a length up to 40 feet, with a content of potassium chloride somewhat less and an iodine content somewhat greater than the *Nereocystis*. A fair but conservative estimate of the weight of kelp surveyed in Puget Sound this summer is upward of 200,000 tons and it is reasonably certain that a complete survey of the region would considerably augment this figure. The Puget Sound kelps may be found wherever there is a rocky bottom to furnish anchorage for the "holdfasts" and there is at the same time a rapid tide way. Apparently, it is essential to the growth of the kelp that the plants should be constantly laved in new masses of water. They will not grow well in quiet waters, which fact increases greatly the difficulties of a study of their life history and artificial propagation.

In the neighborhood of Monterey, *Nereocystis* is abundant, but the main kelp is *Macrocystis pyrifera*. This plant here sometimes attains a length of 150 feet. The potassium chloride content of the Monterey kelps is about the same as those of Puget Sound and the iodine content somewhat greater. The tonnage of the kelp surveyed near Monterey is especially difficult to estimate, but lies probably between 80,000 and 100,000 tons. As to how much this estimate is likely to be augmented by more complete surveys no definite statement can be made. The groves are relatively small until Point Sur is reached, and it may prove more desirable to gather the kelp in this region for local use as an organic manure, rather than to attempt to utilize it for factory manipulation and preparation of commercial fertilizers. Further information regarding this region is very desirable.

From Point Sur south to Magdalena Bay occur large and frequently very dense groves of kelp. By far the most important variety is *Macrocystis pyrifera*, the next in importance being *Pelagophycus porra*, with other varieties negligible in an economic sense. The groves in this region are on the exposed shores of mainland and islands where there are rocky bottoms and continued movement of water. *Macrocystis* grows generally at depths of 6 to 10 fathoms. *Pelagophycus*, called locally elk kelp and sometimes bull kelp, is found also in deeper waters, 12 to 18 fathoms. It is frequently 90 feet in length and sometimes considerably longer. The groves in this region are often very large and very dense. Groves have been observed 5 miles in length and 1 or 2 miles in breadth. This past summer the area surveyed was about 85 square miles, of which over 20 square miles was of very heavy growth. The area surveyed was

probably not half the area of the groves from Point Sur to the Mexican line and certainly less than a quarter of all the groves from Point Sur to Magdalena Bay.

The analyses of San Diego kelps, made this summer, indicated that they contained somewhat less potassium chloride than do the more northern kelps. That this is actually the case is doubtful, and is a conclusion that should be held in reserve, pending further data. It does seem that the San Diego kelps run higher in iodine than the more northern kelps. The enormous areas of the San Diego groves and their ready accessibility make them especially valuable. The tonnage surveyed this summer was probably about 8,000,000 tons.

The principal kelp of the northern Pacific waters is *Nereocystis*. This plant is an annual, a fact of the utmost importance for its commercial exploitation. To harvest it at its best, and with due regard to the maturing of its spores and the maintenance of the groves, requires a nice judgment.

Rigg concludes that it would be wise to refrain from harvesting in the Puget Sound until after July 15. Whether this date would be the optimum for Alaskan waters or those south of Cape Flattery must be determined by further observations. It is at least clear that a "closed season" should be maintained for this kelp and its congeners, and there should be no further delay than is absolutely necessary to provide official supervision and policing of *Nereocystis* groves. With the *Macrocystis*, which forms the principal groves of the southern Pacific waters, the case is somewhat different. This plant is probably perennial, although there is some uncertainty as to this fact. At least the plant lives for more than a year. Considering the fruiting processes of this plant, described in technical detail in the appendices, it seems perfectly safe to cut it at least twice a year. It is claimed by many observers that if the fronds only of *Macrocystis* are cut away, and the stipes and holdfasts are not seriously disturbed, the plants will reproduce in from 40 to 60 days practically as heavy a growth as before the cutting. This point is now under observation. Possibly it would be wise to fix a date after which cutting should not be permitted, at least for some months. In other words, a "closed season" may be found desirable for the *Macrocystis* groves.

Supervision and possibly policing of the groves may be desirable for further reasons. If exploiters are permitted to tear out the plants, the groves may soon be depleted or entirely destroyed. If, however, the plants are cut at not to exceed 10 or 12 feet below the surface, the groves may be maintained indefinitely. Moreover, this depth is apparently the limit to which cutting devices may be made effective on a large scale. The desirability of supervising and policing the kelp groves is a matter of sufficient importance to justify immediate and serious consideration from the constituted authorities, and attention is called to the opinion of the Solicitor of the department, given in Appendix I.

The cutting and gathering of the kelp has not as yet been met with completely satisfactory results, and this is apparently the one detail lacking to insure success to the kelp industry.<sup>1</sup> A number

<sup>1</sup>One company operating on the Pacific coast claims to have met this problem successfully. A device which might be employed is described in the Twelfth Annual Report of the New Jersey State Experiment Station, 1891, p. 201, and the Twenty-first Annual Report, 1900, p. 359.

of mechanical devices have been suggested, and some of these have been tried out, but with moderate and qualified success. The problem is a purely mechanical one, with no theoretical difficulties, so far as can be seen. It is reasonably certain that American ingenuity will solve the problem. It can hardly be considered even a serious one in forecasting the possibilities of a kelp industry.

The data available is not sufficiently detailed to permit of an accurate forecast of the value of the kelp industry, or even a close approximation to it. It is entirely sufficient, however, to give an idea of the limits between which the probable true value lies.

The tonnage of kelp actually seen and mapped this past summer, if cut to a depth of 8 feet, was certainly in excess of 8,000,000 tons, containing at least 400,000 tons of potassium chloride, corresponding to 5 per cent of the wet weight or 30 per cent of dry, worth at present prices upward of \$16,000,000, or considerably more than the value of our present importations of all potassium salts. But excluding what may be found to exist in Alaska, it is very probable that less than a fourth of the standing kelp was mapped, and a vast majority of the important groves could be safely cut twice a season, so that it does not appear extravagant to say that the Pacific kelps at their best can yield over 6,000,000 tons of potassium chloride, with a value at present prices well over \$240,000,000. There would also be recoverable over 19,000 tons of iodine, worth at current prices over \$95,000,000. No such quantity of iodine is, nor so far as one can see, ever likely to be used. Importations appear to be irregular, but it would probably be conservative to say that even with much cheaper iodine only \$1,000,000 worth annually can be marketed in this country, the cost of production being only a small fraction of this sum. Finally, admitting that the foregoing estimates may be extreme and taking all factors into consideration, it is certainly safe to say that the Pacific kelps can easily be made to yield upward of 1,000,000 tons of potassium chloride annually, worth at least \$35,000,000, and that the cost of production can largely, if not entirely, be covered by the value of the iodine and other minor products. The value of the present annual importations of potash salts from Germany is, in round numbers, \$12,500,000.

The food value of kelp is often questioned. Kanten, or agar-agar, or simply agar, is a gel produced from certain varieties of the *Gelidia*. These are, however, rock weeds rather than kelps, and have no importance in a consideration of the industrial uses of kelp. Kombu is produced by extracting the mineral salts from some varieties of *Laminaria*, drying and grinding or shredding the residue. In itself kombu seems to have but little food value, but is the basis of a number of dishes greatly affected by the Japanese. Inquiry among the Japanese merchants on the Pacific coast brought conflicting testimony, but it is probable that a small amount of kombu is now made in the United States. At the best it can hardly ever become more than a minor industry.

The giant kelps which are of value as a source of potash present another question. In Alaska it is reported that cattle will eat the kelps quite readily, and there are occasional (though unofficial) reports of cattle having eaten the kelps of California. This suggests a possible utilization of the organic tissue of the kelps after the

mineral salts have been extracted by water. Analyses of the kelps, however, show them to have on the average quite a low content of nitrogen, and presumably therefore of proteins, although kelp compares well with hay. It is very doubtful if the leached kelps would have any value as cattle feed other than as a "roughage" to be mixed with other feeds.

Papers have been made from the organic constituents of Pacific kelps, some of unusual beauty and desirability as writing papers. The kelps lack fiber, however, and this must be supplied from some other source. Some of the desert plants, as the common yucca of southern California, have been used in this way experimentally and with apparently very good results. It is not probable, however, that kelp papers are to attain any great commercial importance so as to affect materially the use of kelp as a source of potash and iodine.

The cutting of the kelp groves has been opposed to some extent on two grounds. It has been suggested that it might affect disastrously the fishing. But the United States Fish Commission and such eminent authorities as Jordan have expressed the opinion that no food nor bait fishes of any economic importance frequent the kelp groves. Moreover, if the cutting of the kelps is confined to the surface material, as it should be, it seems altogether improbable that it could have any material effect on the fish life below. The second objection is that the cutting of the groves, and especially the larger groves along the lower California shores, will destroy a natural protection or breakwater, with possibly dire results from increased wave action, loss of harbors, abandonment of refuges for fishermen who run behind the kelp beds in heavy weather. This objection seems to have some real foundation, but has undoubtedly been much exaggerated. Probably no harbor of any importance would be seriously affected other than Santa Barbara, and even here it is very doubtful, if the kelp is properly cut, since the remaining stipes would still retain a great moderating influence on the seas. Moreover, the harvesting of the kelp would be done probably at a season which would allow a renewed growth for protection purposes before the season of bad weather. While satisfactorily positive statements can not be made regarding this matter until some actual experience has been accumulated, it is probable that the value of the products from the harvested kelp would far more than compensate any untoward consequences which may reasonably be anticipated.

In Europe it has been the practice to burn the kelp in piles on the shore. Much loss of potash and iodine resulted, and the residue contained much sand and formed lumps and cakes difficult to handle. Ovens or retorts have been tried there to a very limited extent, enough to show that better results could be obtained. European experience, however, is of little value in predicting the best practice for the Pacific coast of the United States, where conditions of labor, fuel, and other factors of economic importance are quite different.

Burning in ovens or retorts undoubtedly gives a better yield of potash and iodine. With a closed retort there is produced a mixture of gases of high illuminating and heating value, which can be utilized in the heating of the retort itself or other retorts for the drying of kelp in preparation to its being burned, for the evaporation of aqueous lixiviates, or the generation of power. Tarry products and

oils are formed to some extent which can be readily collected. These probably will be found to have an economic value, although they have not been yet satisfactorily exploited. If the heating has been judiciously conducted, there is also found a charcoal of exceptional absorbtive and other physical properties, which gives it a commercial importance. On account of the careful heating required, oil is to be preferred as a fuel, and this, fortunately, is at hand on the Pacific coast in quantity and at a low figure. If the heating be not carefully controlled the melt is apt to cake badly and include many partly burned fragments. To get around this trouble, various infusible substances in lump can be introduced advantageously. Balch has proposed lime, and rock phosphate has been suggested as yielding, after lixiviation, a more valuable residue. In the latter case the production of charcoal is abandoned.

Burning in the open oven or one planned to permit the passage of air again utilizes quite well the heat value of the kelp which may be employed advantageously for drying and evaporation purposes. Combustible gases and charcoal are, however, lost, but satisfactory melts are obtained. Which is the more economical in cost of handling, open oven or closed retort, is yet to be determined, although both yield satisfactory melts. Both forms lend themselves readily to engineering arrangements for economical factory practice.

When a properly burned melt is lixivated and the mother liquor evaporated, postassium chloride crystallizes from the solution quite pure and in quantity, a mother liquor resulting which contains a mixture of salts, containing the chlorides and sulphates of sodium and magnesium, and including the iodides.

Several methods suggest themselves for recovering the iodine. The mother liquor may be brought to dryness mixed with powdered pyrolusite and treated with sulphuric acid, as in the well-known laboratory procedure. Where chlorine is available it may be used to liberate the iodine from the concentrated mother liquor, the iodine being extracted in various ways, as by carbon tetrachloride, etc. This is also a well-known laboratory procedure which can be easily adapted to factory practice. Another method which commends itself to consideration is to bring the mother liquor in contact with an extractive, like carbon tetrachloride, chloroform, carbon disulphide, or benzene which will form a two-liquid layer system; acidify with sulphuric acid and add some oxidizing agent as chromic acid, a permanganate or ferric sulphate. On agitation the iodine is taken up by the extractive which can be used repeatedly with fresh portions of mother liquor, thus concentrating the iodine from a number of melts.

Still another method has been studied which may be practicable where cheap electric current is available. The kelp plant or the ash either, as may be desired, is placed between porous septa on either side of which is clear water. Electrodes are introduced into the water chambers and a current passed. A very low amperage and a moderate voltage only are required, so that the cost of current is not high. Potassium hydrate collects in the cathode solution from which it can be readily recovered as the carbonate or any other desired salt. Promptly, as the current starts to pass, iodine appears in the anode chamber and probably is very completely segregated there. A little later, however, free chlorine begins to come off from

the anode compartment and the iodine is soon oxydized to iodic acid. The recovery of the iodine from the anode solution, as such or as potassium iodide, is a very simple matter.

#### THE COST OF POTASH FERTILIZERS.

The cost of imported Stassfurt salts is increasing. This fact alone would be a sufficient justification for the investigations here recorded. But to this fact must be added the far more important one that the economic and social rearrangements taking place in the country make imperative a determination of our native resources. So far the data gathered justify the conclusion that there are two possible sources of potash salts in the United States of present economic importance. These are the Pacific kelp groves and the alunite deposits of Utah, Nevada, and Colorado. That potash silicates, brine residues, or other sources may in time have a large commercial importance is possible, even though appearing improbable at present. That some of them may have a local importance and be good financial investments in a minor way is quite probable.

To estimate the cost of producing a ton of potassium chloride at one of the Pacific ports is yet not feasible. There is a small factory in operation for this purpose, with a reputed capacity of 6,000 tons annually. It is operating under a secret process, depending for success upon a secondary product, is making no serious effort to recover the iodine, and is largely in an experimental stage both as regards the harvesting of the kelp and its manipulation in the factory. The experience there obtained shows little as yet regarding the possible cost of producing potassium chloride.

In so far as can be judged from a priori considerations, it should be possible to produce potassium chloride from kelp at practically no cost, since the iodine and other minor products should at least equal in value the cost of manipulation. There is no sound assurance, however, that this is the case. Carefully obtained engineering observations and computations are yet needed. And existing trade relations—for instance, those affecting the iodine market—may require time-consuming and otherwise difficult readjustments or developments. Nevertheless, it can not be doubted that potassium chloride can be produced on the Pacific coast in quantity and sold at a price very low as compared with the current prices on the Atlantic coast. Probably, also, the product obtained from Pacific kelp could be placed on the Atlantic coast at a price substantially lower than is now current, and certainly this should be the case when the opening of the Panama Canal makes possible a water shipment practically from factory door to Atlantic distributing points. Authoritative statements of the cost of production of potash salts at the Stassfurt mines are not, naturally, easily accessible. Enough is known, however, to justify a decided opinion that greatly increased tonnages at prices half or less than now prevailing could be laid down at American ports should there be any real threat of competition from native sources.

In the case of alunite, quite different conditions prevail. It is very doubtful if the product mined from any known American sources would average 10 per cent potash. But assuming that it ran even somewhat higher, and 20 per cent potassium sulphate were

obtained, then more than 5 tons of material must be mined and treated for every ton of salt produced. This means a large initial cost for mining and preparation of material. It also indicates that only a very large and a relatively rich deposit is worthy of any serious commercial attention. A limited market for alumina and the prospect of cheap sulphuric acid from smelter fumes negate the hopes of by-products alone paying the cost of manipulation. Nevertheless, it seems quite probable that potassium sulphate from alunite might be produced in Utah, and possibly elsewhere, at a cost less than half the current price on the Atlantic seaboard plus transportation charges. Here, again, there are necessary further data from field and laboratory and engineering considerations for which the existing data are entirely insufficient.

In so far as present information goes, the Pacific kelp groves are and probably will remain by far the most important American source of potash. In fact, if carefully and skillfully husbanded, they promise to approximate and perhaps even surpass, in importance and value the famous Stassfurt mines. Alunite, important as it is, falls far behind. Aside from all other potash salts, the present annual importation of potassium sulphate is upward of 50,000 tons. To equal this, at least 250,000 tons, and probably much more, alunite would have to be mined and treated each year. To take out of the ground this much material, aside from providing fuel, water, labor of manufacture, and other necessary items, is no mean problem. Increasing mining costs with increasing depth of shafts and drifts, or increasing mass of overburden seems to be inevitable. Possibly these difficulties can be met, but at the best alunite promises to be a minor if nevertheless important American source of potash.

Finally, while the conclusion is justified that kelp groves and alunite can be exploited commercially and even, perhaps, at large profits, it is by no means to be assumed that any particular proposition which may be promoted is safe and desirable. Prospective investors are again urgently warned to hesitate until they have obtained such information as may be given by public officials and the advice of a reliable and disinterested chemist or engineer who has carefully inspected the particular proposition in view.

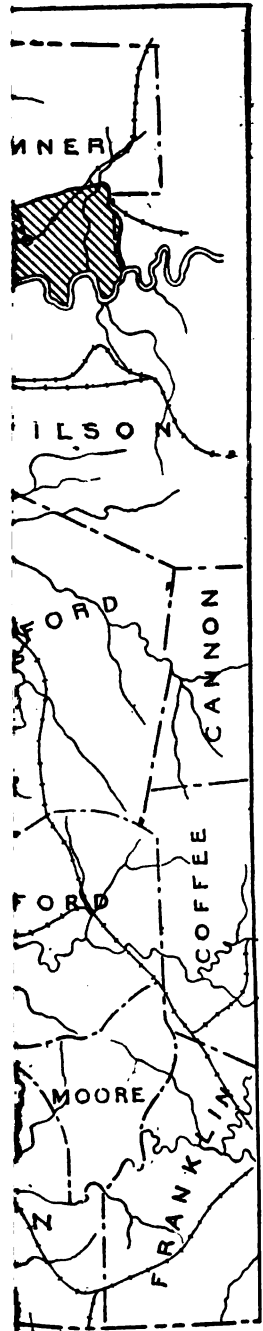
#### CONCLUSIONS.

To the foregoing report and as integral parts thereof are appended tables, special reports, reference lists, and maps containing more detailed data. From the data as a whole are deduced the following conclusions:

1. A much increased production and wider use of commercial fertilizers must accompany or closely follow the economic changes and readjustments now taking place in the United States.
2. The United States has within its borders supplies of raw materials for standard types of fertilizers. These supplies will be ample for a long but indefinite period.
3. Official investigation, supervision, and control of natural supplies of raw materials are very desirable—to prevent undue wastage, to encourage legitimate manufacturing, and to conserve the interests of the lay public, especially of farmers and small investors.







## **APPENDIX A.**

### **A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS.**

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#### **NATURAL PHOSPHATES OF TENNESSEE.**

##### **INTRODUCTION.**

The phosphate deposits of Tennessee rank next in importance to those of Florida. Much work has been done in these fields and valuable geological and chemical reports have been published.

It is the purpose of this report to describe conditions in these fields, to outline the modern methods of mining and handling the rock, and to show what disposal is being made of the finished product and waste material or by-products of the industry.

The conditions in the Tennessee fields have changed considerably within the last few years, mining methods have improved, deposits of lower grade rock are being exploited, and many of the old mines and dumps are being reworked.

##### **GEOGRAPHY AND TOPOGRAPHY.**

Tennessee is well situated for the distribution of fertilizer material to the Southern and Middle Western States. Its phosphate deposits occur in what is known as the Central Basin of Tennessee (elevation 600 feet) and in the valleys of the western part of the Highland Rim (elevation 1,000 feet) surrounding this basin.

The Central Basin extends across the State from north to south, lying between the Cumberland Plateau on the east and the Tennessee River on the west. It covers an area of approximately 7,000 square miles of gently undulating country. The phosphate deposits have been developed only in the western part of this area, workable beds lying in parts of Sumner, Davidson, Williamson, Lewis, Maury, Hickman, and Giles Counties. (See fig. 1.)

The main streams in the phosphate regions are the Cumberland, Duck, and Tennessee Rivers, but there are numerous creeks and tributaries of the Duck River that are of great importance in the development of the deposits, as sources of water supply for mining and handling the rock.

Both the Cumberland and Tennessee Rivers have been utilized for transporting phosphate rock, but mining in the vicinity of these streams has practically ceased and no recent shipments have been made. Considerable material will probably be shipped down the Tennessee River in the near future, following the development of the white phosphate deposits of Perry and Decatur Counties.

Most of the mines are reached by the Louisville & Nashville, the Nashville, Chattanooga & St. Louis, and the Middle Tennessee Railroad.

#### GENERAL GEOLOGY.

All the exposed strata of these regions are of sedimentary origin. The phosphate occurs in rocks of Ordovician and Devonian age. Table I, compiled from the report of Hayes and Ulrich<sup>1</sup> on the Columbia quadrangle, which covers parts of Williamson, Hickman, Lewis, and Maury Counties, gives the stratigraphic position of the various phosphate beds and their relation to the overlying, surrounding, and underlying formations.

TABLE I.—*Geologic formations in the Columbia quadrangle, Tenn.*

Age.	Formation.	Description.
Carboniferous.....	St. Louis limestone.....	Gray and blue cherty limestone.
	Tullahoma formation <sup>1</sup> .....	Very cherty shale.
Devonian.....	Chattanooga shale.....	Carbonaceous black shale. (Phosphate horizon.)
	Clifton limestone.....	Even-bedded, compact, gray or blue limestone.
	Fernvale formation.....	Soft green or brown shale with bands of crystalline limestone.
Silurian.....	Lepers formation.....	Knotty, earthy limestone and interbedded shale. (Phosphate.)
	Catheys formation.....	Knotty, earthy limestone and shale with bands of blue limestone. (Phosphate.)
	Bigby limestone.....	Granular, crystalline, laminated phosphatic limestone. (Phosphate.)
Ordovician.....	Hermitage formation.....	Shale with siliceous limestone below and phosphate limestone above. (Phosphate.)
	Carters limestone.....	Massive, compact, white or blue cherty limestone.
	Lebanon limestone.....	Thin-bedded, compact bluish limestone.

<sup>1</sup> Since the publication of the Columbia folio this formation has been correlated with the Fort Payne chert, the older name, and "Tullahoma" has been abandoned by the U. S. Geological Survey.

Table I shows four formations in the Ordovician rocks which contain phosphate beds. It must be understood, however, that these formations are not always in normal succession, some of them being absent in certain areas, nor are the beds always highly phosphatic. Local conditions during their deposition and subsequent changes have caused wide divergence in composition.

#### CLASSES OF PHOSPHATE.

There are three economically important classes of phosphate rock in Tennessee, namely, the brown phosphate or Ordovician rock, which is divided by Hayes and Ulrich into several groups; the blue, or Devonian phosphate, of which there are several classes, and the white rock deposited from solution in caverns. The nodular and conglomerate phosphates, though widely distributed, are not found in sufficient quantities to be profitably mined by themselves. Each of the three classes mentioned will be treated separately.

#### BROWN-ROCK PHOSPHATE.

##### LOCATION OF DEPOSITS.

Workable deposits of brown-rock phosphate are found scattered over a very wide area, as many different beds occur in the several formations of Ordovician age. The most important are those in

<sup>1</sup> Columbia Folio, No. 95, U. S. Geological Survey, 1903.

Sumner, Davidson, Williamson, Hickman, Maury, Lewis, and Giles Counties. Most of the mines are reached by the Louisville & Nashville and the Nashville, Chattanooga & St. Louis Railroads, but several of the deposits being worked in Hickman and Davidson Counties are several miles from the railroads. The brown-rock deposits west of Nashville, in Davidson County, and those of Sumner County, in the vicinity of Gallatin, have easy access to the Cumberland River.

#### GEOLOGICAL OCCURENCE AND ORIGIN.

All of the Tennessee brown-rock phosphate occurs in rocks of Ordovician age. There are numerous phosphatic horizons in this series, some of which frequently occur so close together that they can be mined as a single bed. Taken in order of their stratigraphic succession, the phosphate bearing rocks are given in Table II.

TABLE II.—*Geologic formations in west-central Tennessee, which carry brown-rock phosphate.*

Age.	Formation.	County where found.
Ordovician.....	Leipers formation.....	Lewis, Hickman, Sumner.
	Cathays formation.....	Maury, Hickman (unimportant).
	Bigby limestone.....	Maury, Giles.
	Hermitage formation.....	Maury, Williamson, Davidson.

The deposits of brown phosphate are generally conceded to be formed by the leaching of phosphatic limestones by carbonated waters. The solution and removal of carbonate of lime has been attended by a diminution in thickness and consequent settling of the phosphatic strata. Some secondary deposition has also taken place in the pores and interstices of the leached mother rock.

The phosphate beds occur in two distinct forms, known as collar and blanket deposits. The first occurs where the horizontal phosphatic limestone stratum outcrops on the slope of a steep hill. The stratum passes through the hill but has been leached only at the outcrop, the overburden of younger rocks protecting the main part of the bed from the action of percolating waters. This class of deposit has proved very deceptive to the miner, who, finding the outcrop a very high grade phosphate rock, has tunneled into the hill to discover that the stratum passes rapidly to a phosphatic limestone.

The blanket deposits, on the other hand, sometimes cover wide areas. They usually lie near the surface of gently undulating hills where the underdrainage is favorable to their formation. Almost ideal conditions existed in the Mount Pleasant regions for the production of such deposits.

In this section the highly phosphatic Bigby limestone lies very near the surface and is underlain by an easily soluble fine-grained limestone through which the percolating water readily drained. The leaching began where the surface water gained access to the beds along the joint planes, but gradually worked through the entire mass, carrying away the carbonate of lime in solution and leaving the less soluble phosphate of lime.

The blanket deposits are always more or less wavy in their character, owing to the irregularity of the leaching. Large columns,

bowlders, and cones of unaltered phosphatic limestone occur throughout these deposits. In Plate I, figures 1 and 2, are shown strata and bowlders of phosphatic limestone, with the leached brown phosphate occurring both above and below them.

There is also a secondary tufaceous brown phosphate which occurs in the Hermitage formation, but it occurs in very small quantities, is essentially a pocket formation, and is of no great economic importance.

According to Hayes and Ulrich,<sup>1</sup> the limestone from which the brown phosphate is derived was probably deposited in a sea so shallow that the bottom was affected by wave action and currents. These authors consider the deposits to be largely of organic origin and to consist of the remains of phosphatic and carbonaceous shellfish. The carbonate of lime was partly replaced by the phosphate, forming beds of more or less phosphatic limestone, which upon being elevated above the surface were further enriched as outlined above. Brown<sup>2</sup> and Ruhm<sup>3</sup> agree with Hayes and Ulrich in their theories as to the origin of the Ordovician phosphate.

#### PHYSICAL PROPERTIES.

The Ordovician phosphate varies considerably according to location. The beds derived from the different formations have definite characteristics which aid the geologist and mining engineer in identifying the horizon. The rock varies in color from a light gray to a deep chocolate brown and in texture from a porous rock, disintegrating into phosphatic sand, to a hard, close-grained rock very resistant to weathering. As a whole the rock is brown or gray and occurs in plates of varying thickness. The beds vary in thickness from a few inches to 20 or 30 feet, with an average of 6 to 8 feet. The mean specific gravity of the Tennessee brown rock is about 2.8. The yield of phosphate per foot per acre is from 600 to 1,000 tons.

In Table III are given the results of analyses of different types of brown-rock phosphate, the samples being taken in several localities:

TABLE III.—*Analyses of samples of Ordovician brown-rock phosphate from Tennessee.*

No.	Location.	Thick- ness of bed.	Geologic formation.	P <sub>2</sub> O <sub>5</sub> .	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> .
		<i>Feet.</i>		<i>Per cent.</i>	<i>Per cent.</i>
3 and 5	Mount Pleasant, Maury County.....	3	Bigby.....	34.50	75.42
46	Near Nashville, Davidson County.....	4	Hermitage.....	34.32	75.02
70	Centerville, Hickman County.....	3	Leipers.....	35.79	78.21
76	Near Centerville, Hickman County.....	40	.....do.....	35.01	76.33
39	Near Gallatin, Sumner County.....	6	.....do.....	23.62	51.62
40	Wales Station, Giles County.....	8	Bigby (disintegrated).....	31.11	77.98

#### METHODS OF MINING.

Only within the last few years have modern mining methods been employed in the Tennessee phosphate fields. For years the richest deposits of brown rock in the Mount Pleasant regions were worked

<sup>1</sup> Columbia Folio No. 95, U. S. Geological Survey, 1903.

<sup>2</sup> Engineering Association of the South, Trans., 15, 93-94 (1903-4).

<sup>3</sup> Engineering and Mining Jour., 88, 522 (1907).

by hand, and only when these deposits were considered to be nearly exhausted did the operators seem to realize the crudity, wastefulness, and inefficiency of the methods they were using. Even now a few small firms and farmers are employing the pioneer method of shaking out all rock not held by the tines of a potato fork and drying the larger pieces in the sun or on ricks of wood.

The larger operators have adopted much more thorough and economical methods of working the deposits. The overburden is first removed by steam shovels or scrapers, and the phosphate rock, together with its matrix, dug out with picks and forks, loaded into tramcars, and hauled to the washer, where it is put through a cleansing process described below. In the vicinity of Centerville they have installed the hydraulic system of mining which has been used so successfully in the Florida land pebble regions. By employing a screen to prevent large pieces of rock from entering the centrifugal pump this method is expected to prove very satisfactory. The Tennessee phosphate regions have distinct advantages over those of Florida for hydraulic mining, as the Tennessee product occurs in the hills, where the overburden can be disposed of by gravity. The rock itself does not have to be pumped to a great height, as is the case in many of the Florida mines, where the pits are so far below the level of the washer plant. Plate II, figure 1, shows the method of mining brown-rock phosphate.

The modern Tennessee washing plants differ considerably in some features, but the general scheme of separating the phosphate from its impurities is the same with all of them. The phosphate rock, together with the matrix in which it is frequently embedded, is brought from the mines in tramcars, hauled to the top of the washer, and dumped into a hopper. Streams of water are played upon the mass, washing the material down to a crusher, which breaks up the larger lumps of rock. From this point it either goes through a log washer similar to that employed in the Florida phosphate fields,<sup>1</sup> or is conveyed over a series of screens by a kind of chain scraper.

The material passing through these screens then goes to the revolving rinser, where it is thoroughly sprayed. The portion passing through the half-inch perforations of the rinser falls into a hopper, is taken up by pumps and passed through a series of settling tanks, being finally discharged into the draining bins. After the water has partly drained off the washed product is drawn out and sent to the driers. Plate II, figure 2, shows one of the most modern types of phosphate washers.

Where the log washer is employed, the backwash, together with the overflow from the settling tanks, is led through troughs fitted with riffles to catch the finely divided phosphate. The clay and other impurities held in suspension with very finely divided phosphate is finally discharged into waste ponds. This method of washing has proved so efficient that many of the old deposits are being reworked and a very high grade product obtained.

In Table IV a comparison is made of the coarser rock which was saved by the old mining methods and the fine material formerly thrown out, but which modern washer plants have now made it profitable to mine.

<sup>1</sup> Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr., 1910.

TABLE IV.—*Analyses of coarse and fine, washed, Tennessee brown phosphate.*

Location.	Coarse fragments.		Rock fragments, less than one-half inch diameter.	
	P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
Charleston, S. C., Mining & Manufacturing Co., Mount Pleasant, Tenn.	<i>Per cent.</i> 33.50	<i>Per cent.</i> 73.23	<i>Per cent.</i> 34.32	<i>Per cent.</i> 75.01
Volunteer State Co., Centerville, Tenn.	35.01	76.33	33.23	72.64
International Agricultural Corporation plant, Mount Pleasant, Tenn.	36.91	80.65	35.72	78.05

The old kiln method of drying phosphate on ricks of wood is still employed to some extent in the brown-rock region, but is used only for the larger plates or fragments of rock. A few small operators still dry their rock in the sun, but the output of material dried in this way is very small.

Most of the rock is dried in rotary cylinders, which are so largely employed in the pebble regions of Florida.<sup>1</sup> Some of the miners prefer to feed their phosphate rock into the hottest end of the drier—that is, the end in which the flames and gases of combustion enter—while others introduce the phosphate into the cooler end of the cylinder and allow it to work toward the hotter end. The latter method seems on the whole more efficient and economical, since the partly dried rock does not come in contact with atmosphere highly charged with moisture, and there is also probably less danger of loss of finely divided rock through the stack. Kentucky coal is used as fuel.

#### COST OF PRODUCTION.

The cost of preparing brown-rock phosphate for the market has increased considerably in recent years. When the rock was first mined no plant was required to treat the phosphate, hand labor was employed, and a few rough sheds were erected in which to store or dry the material. At that time thousands of tons were mined at a cost not exceeding 75 cents per ton.

With the increased cost of labor and fuel and the expense of erecting washing and drying plants, the cost of production has advanced greatly. In the Mount Pleasant district, where the old deposits are being reworked, and in Giles County, where the phosphate is in a disintegrated condition, much waste material has to be handled to obtain a high-grade product. It is also necessary to remove a much heavier overburden than formerly to reach the phosphate deposits. Many of the operators find it profitable to remove 4 feet of overburden for every foot of underlying phosphate. The average cost of taking off this overburden is 15 cents per cubic yard, though it is claimed that where hydraulic methods are employed it can be removed at a much lower figure.

On account of these numerous factors the average cost of producing high-grade rock for the fertilizer trade is not far from \$2.50 per ton.

<sup>1</sup> Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr.; Menninger, C. G., Eng. News, 60, 1908.

## MARKETING OUTPUT.

The current freight rates from the principal mining districts in the brown-rock regions to the manufacturing cities and markets are given in Table V.

TABLE V.—*Freight rates on phosphate rock (lump rock) per long ton.*

Location of deposit.	Destination.	Rate per ton.
Mount Pleasant, Columbia, and vicinity; Wales and vicinity, Franklin, to.....	Cincinnati, Ohio.....	\$2.50
	Cleveland, Ohio.....	3.80
	Columbus, Ohio.....	3.40
	Louisville, Ky.....	2.25
	Indianapolis, Ind.....	3.10
	Atlanta, Ga.....	2.45
	Montgomery, Ala.....	1.75
	Savannah, Ga.....	3.75
	Cincinnati, Ohio.....	2.25
	Cleveland, Ohio.....	3.55
Gallatin and vicinity to.....	Columbus, Ohio.....	3.15
	Louisville, Ky.....	2.00
	Indianapolis, Ind.....	2.85
Centerville and vicinity to.....	Cincinnati, Ohio.....	2.50
	Nashville, Tenn.....	1.75

<sup>1</sup> Ton of 2,000 pounds.

Most of the brown-rock phosphate mined in Tennessee is disposed of in this country, though a considerable quantity of the highest grade—rock containing from 78 to 80 per cent  $\text{Ca}_3(\text{PO}_4)_2$ —is shipped abroad.

The fertilizer trade (manufacturers of acid phosphate) demands a rock containing not less than 72 per cent bone phosphate of lime ( $\text{Ca}_3(\text{PO}_4)_2$ ) and not more than 5 per cent iron and alumina. This produces an acid phosphate containing 16 per cent available phosphoric acid.

Within the last few years the sales of ground-rock phosphate for direct application to the field have grown considerably. Excellent results have been reported from its use at the Ohio and Illinois experiment stations and from individual farmers. Several companies are handling this product exclusively. The rock is ground to varying degrees of fineness. One company has two grades; No. 1 is ground so that 90 per cent will pass a 60-mesh sieve and No. 2 ground so that 95 per cent will pass a screen containing 100 meshes to the inch. The ground rock is sold on a guaranty of 60 to 65 per cent bone phosphate of lime ( $\text{Ca}_3(\text{PO}_4)_2$ ) and shipped chiefly to States in the Middle West.

In Sumner and Hickman Counties new phosphate fertilizers are being prepared. The processes are patented and the manufacturers claim that they obtain a product containing fully as much phosphoric acid as superphosphate, without the objectionable feature of free acid. Under these new processes rather low-grade rock can be used.

## WASTE MATERIAL.

Within the last few years the main sources of waste in the brown-rock phosphate fields have been largely eliminated. When phosphate was first mined in the Mount Pleasant district probably half of the rock was thrown away. Much of this will never be recovered, as it has become mixed with foreign matter and covered by overburden too heavy to make reworking commercially practicable. A large



proportion of the Mount Pleasant deposits, however, is now being worked over. Modern washer plants save upward of 75 per cent of the phosphatic material, recovering much of the finely divided or disintegrated rock. The operators state they can hold and cleanse material fine enough to pass a 60-mesh sieve.

Considerable finely divided phosphate is discharged into the waste ponds. Samples of material taken where the wash water enters these ponds are found to be quite rich in phosphoric acid, but the quality of the deposited residue falls off as the middle and far end of the pond is reached, since the heavier particles, which are mainly phosphate rock, have settled out. Part of these waste ponds can and doubtless will be worked over to advantage.

In putting the rock through the mechanical dryer considerable phosphate dust is carried up the flue and out of the stack by the powerful draft. Many of the stacks are now provided with hoods and baffles to catch these "floats." Weather conditions affect the amount of material thus carried up the flues, but, roughly figured, about 2 tons of "floats" are saved by these hoods for every 100 tons of rock charged to the dryers.

The limestone "horses," or unbleached phosphatic limestones, occurring in most of the brown-rock phosphate beds frequently contain a high percentage of phosphoric acid. No attempt has been made as yet to utilize these boulders, although they would be valuable when ground, as they contain a considerable quantity of lime phosphate mixed with lime carbonate. Under the present method of mining the phosphate is dug from around these boulders and the pits are then either abandoned or filled in with overburden from adjoining deposits. These boulders could be removed, broken up, and crushed at small cost, and would prove of considerable value as fertilizer material.

Another method of utilizing these phosphatic limestones would be to burn them in a kiln, afterwards slaking them with steam or hot water. There is frequently sufficient carbonate of lime present to make this a practical means of disintegrating the rock.

In Table VI the phosphate content of a number of samples of phosphatic limestone before and after burning are given. These samples were first dried for several hours at 100° C. and then analyzed. They were then heated to the highest temperature obtainable with a blast lamp until they ceased to lose in weight, and again analyzed.

TABLE VI.—*Analyses of phosphatic limestone, underlying phosphate beds, and boulders before and after burning.*

No.	Location.	Content of $P_2O_5$ .	
		Before burning.	After burning.
		<i>Per cent.</i>	<i>Per cent.</i>
2	Mount Pleasant, Tenn., underlying limestone.....	16.05	21.15
4	do.....	9.48	11.12
6	do.....	19.43	21.42
8	do.....	18.30	23.80
11 W	Near Mount Pleasant, Maury County.....	12.53	21.15
47	6 miles west of Nashville, Davidson County.....	22.97	27.06
65	2 miles north of Centerville, Hickman County.....	14.69	19.75
75	do.....	16.32	17.72

In Table VII there are given the results of some experiments carried on in cooperation with L. R. Coates, of Baltimore, Md., the object of which was to test the slaking properties of phosphatic limestones after heating to various temperatures.

The samples grouped opposite A were burned at the temperatures indicated in column 2 and sent to the laboratories of this bureau. Here they were then slaked and sifted, and the percentages of the several sized particles determined. Each was then analyzed for phosphoric acid.

The samples under B were all burned and analyzed in the physical laboratory of the H. S. Spackman Engineering Co., Philadelphia, Pa. It is understood they were ground before being burned. This fact no doubt accounts for the small percentage of nodules in the samples.

TABLE VII.—*Mechanical and chemical analyses of phosphatic limestone after burning and slaking.*

1	2	3	4	5						6
Sample No.	Temperature.	Time of heating.	Loss on heating (percent).	Percentage of separates after heating and their phosphoric acid content.						CaCO <sub>3</sub> in nodules (per cent).
				Nodules.	P <sub>2</sub> O <sub>5</sub>	0.1-25 mm.	P <sub>2</sub> O <sub>5</sub>	0.1 mm.	P <sub>2</sub> O <sub>5</sub>	
A.										
Check for 1 and 2.....	C°	Not heated.....		100	22.80					
1.....	800-812	7 hours.....	15.30	55+	27.24	26+	27.96	18+	24.00	7.45
2.....	909-914	do.....	15.50	38+	29.04	28+	28.44	33+	24.28	5.65
Check for 3.....		Not heated.....		100	24.56					
3.....	700-705	7 hours.....	8.40	78+	25.88	13+	29.72	9+	26.24	26.86
B.										
Check for 4, 5, 6, and 7.....		Not heated.....			24.56					
4.....	700	15 minutes.....	18.15	4+	18.00	36+	27.16	58+	24.68	
5.....	800	do.....	18.23	1+	26.96	28+	29.16	69+	24.28	
6.....	900	do.....	18.90	6+	25.20	41+	26.44	52+	22.08	
7.....	1,000	do.....	18.95	3+	26.76	43+	28.60	53+	22.16	

In every instance (except two, where the temperature was only 700° C.) the percentage of phosphoric acid is lower in the finest of the three grades of separates. This is to be expected from the character of the rock, since the free lime in slaking readily disintegrates. The figures in Table V, A, seem to indicate that slaking takes place much better when the phosphatic limestone has been heated to 900° C. or higher.

Another source of waste is at the picking belt, where the clay balls, flint, and limestone are picked out by hand and thrown away. Unfortunately, a poor class of labor is usually employed for this purpose, and much good phosphate is lost in the operation.

In Table VIII are given the analyses of the various samples of phosphatic material, much of which is wasted in preparing the rock for the market.

TABLE VIII.—*Analyses of material lost in the pioneer methods of mining brown-rock phosphate.*

No.	Location.	Description.	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	FeO <sub>3</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
			<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
12	Arrow mine, Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material discharged into waste pond; sample taken close to mouth of trough. <sup>1</sup>	5.77	4.19	34.32	75.02
22	Property of Interstate Agricultural Corporation at Mount Pleasant, Tenn.	Phosphate, sand, and mud discharged into waste pond.	.....	.....	27.32	59.70
20	Property of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Phosphate, sand, and muck, formerly thrown away, now being worked over.	16.65	6.48	28.22	61.66
16	Arrow plant of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material thrown from picking board—clay balls containing limestone, flint, and phosphate.	35.40	6.17	22.49	49.14
21	Blue Grass plant of Interstate Agricultural Corporation, Mount Pleasant, Tenn.	Sample of floats saved by placing hood over stack—phosphate dust containing carbon.	.....	.....	30.51	66.67

<sup>1</sup> This material will no doubt be worked over and much of the phosphate recovered.

#### PRESENT CONDITION OF THE INDUSTRY.

There are fully 30 companies which own brown-rock phosphate property in Tennessee, but during the early part of 1911 only 15 of these were actually engaged in mining operations. The combined capacity of the 15 operating plants was about 900,000 tons per annum, but few were running full time and many only intermittently.

Brown-rock mining is being carried on at or near Mount Pleasant, Columbia, and Southport, in Maury County; near Gallatin, in Sumner County; at Wales Station, in Giles County; near Centerville, in Hickman County, and near Ewells Station, Williamson County.

After several years of depression the brown-rock phosphate industry during 1910 showed considerable activity, resulting in a substantial gain over 1909 in the material marketed. The control of the fields, however, is passing rapidly into the hands of the large fertilizer corporations. These companies have installed modern washer plants and are working deposits which the small operator was unable to handle with limited capital. Mining operations, however, have not resumed their former activity. This is due both to the increased cost of labor and the greater expense of handling the remaining deposits of phosphate. The enormous development in the last few years of the Florida pebble phosphate is also accountable for the falling off in the production of Tennessee rock.

The average price of brown-rock phosphate (72 per cent) f. o. b. mines is about \$3.75 per ton. Apparently the price of this material has reached its level, and wide variations from the price given are not to be anticipated, barring some unusual and unexpected development in the industrial or labor worlds.

Table IX is a summary taken from the report of F. B. Van Horn<sup>1</sup> and shows the production of Tennessee phosphate during the last six years.

<sup>1</sup> Production of Phosphate in 1910, Mineral Resources, U. S. Geological Survey.

TABLE IX.—*Production of phosphate rock of the several classes in Tennessee from 1905 to 1910, inclusive.*

[Long tons.]

Year.	Brown rock.	Blue rock.	White rock.	Year.	Brown rock.	Blue rock.	White rock.
1905.....	438,139	44,031	689	1908.....	374,114	79,717	1,600
1906.....	510,705	35,669	1,303	1909.....	266,298	66,705	.....
1907.....	594,594	38,993	5,025	1910.....	329,382	68,806	.....

## FUTURE OF THE INDUSTRY.

A few years ago the life of the Mount Pleasant phosphate fields was considered limited to six or seven years at most. With the advent of new machinery and modern mining methods many deposits which were regarded as exhausted promise to yield as much high-grade rock as has been removed in past years. Many of the rich deposits are still practically untouched, and it is safe to assume that the brown-rock fields will continue to produce a large tonnage for many years.

## BLUE-ROCK PHOSPHATE.

## LOCATION OF DEPOSITS.

The important deposits of blue-rock, or Devonian, phosphate in Tennessee lie along Leatherwood Creek, in the western part of Maury County, south and east of Centerville, on both sides of Swan Creek, in Hickman County, and in the eastern part of Lewis County.

The mines are reached by the Louisville & Nashville, the Nashville, Chattanooga & St. Louis, and the Middle Tennessee Railroads. The rock is usually dried and then shipped to various points in the South and Middle West. The Duck River is the only navigable stream convenient to the blue-rock fields. Practically no phosphate has been shipped on this river in recent years.

## GEOLOGICAL OCCURRENCE.

The blue-rock phosphate belongs to the Devonian period and occurs in the geologic formation known as the Chattanooga shale. The beds vary in thickness up to 4 feet and differ widely in their content of phosphoric acid in different locations.

The phosphate stratum is usually overlain by a massive blue-black shale or slate, 3 feet or more in thickness, containing at its base phosphatic nodules, and is underlain normally by Silurian limestone. Frequently an unconformity exists which brings the Devonian phosphate directly over the brown Ordovician rock. Under these conditions mining should be carried on very profitably.

The analyses of some typical sections of phosphate from areas where such conditions occur are given in Table X.

TABLE X.—*Analyses and descriptions of phosphate beds from localities where the blue rock directly overlies the brown phosphate of the Leipers formation.*

No.	Location.	Thick- ness of strata.	Description. <sup>1</sup>	Analysis.	
				P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
		<i>Ft. in.</i>		<i>Per cent.</i>	<i>Per cent.</i>
68	Blue Buck mines, 6 miles south- east of Centerville, Tenn.	0 9	Coarse, hard blue rock.....	24.80	54.20
69	do.....	9	Fine-grained, hard blue rock....	27.91	60.99
70	do.....	2 6	Brown phosphate (Leipers for- mation).	35.79	78.21
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	1 3	Coarse, oolitic gray rock.....	25.25	55.18
61	do.....	8	Close-grained, hard blue rock....	32.95	72.01
66	do.....	1 6	Brown disintegrated phosphate (Leipers formation).	32.40	70.82
71	Meridian Fertilizer Factory, 2 miles south of Centerville.	1 8	Coarse oolitic, blue rock (sam- pled in tunnel).	26.44	57.79
72	do.....	1 2	Fine-grained, hard blue rock (in tunnel).	36.66	80.11
(1)	do.....		Brown phosphate (Leipers for- mation).	.....	.....

<sup>1</sup> No sample collected.

According to Hayes and Ulrich<sup>1</sup> the blue-rock phosphate was laid down under conditions somewhat similar to those under which the Ordovician phosphate was deposited, except that the shellfish and organisms from which the deposits are in part derived were more highly phosphatic than those existing in Ordovician times, and consequently the deposits required no subsequent leaching to make them of economic value. Another important factor in the formation of the richer deposits of blue phosphate, according to these authorities, is the highly phosphatic Leipers limestone, which in places directly underlies the Devonian phosphate, and which through leaching and subsequent disintegration has given the blue rock much of its substance.

The beds of the highest-grade phosphate, therefore, are of both primary and secondary origin, consisting of the rolled and leached fragments of Ordovician limestone and the phosphatic remains of Devonian life.

#### PHYSICAL PROPERTIES.

The physical properties of blue-rock phosphate differ according to the conditions of its deposition. The unweathered rock varies in color from a blue black to a light gray, depending on its content of organic matter, and in texture from a hard, close-grained, massive calcareous rock to coarsely oolitic, loosely cemented material, very readily broken up. In general the phosphate-bearing formation may be described as a bluish-gray rock, composed of flattened ovules and the waterworn casts of phosphatic shells. In the fresh state the rock is very hard and difficult to grind. It weathers upon exposure into a rusty-yellow material. The average specific gravity of the rock is about 2.87. This means that a stratum 1 foot thick will run about 3,200 tons per acre.

<sup>1</sup>Loc. cit.

The blue rock, as a rule, has a lower content of phosphoric acid than the brown, but this objection is largely offset by the fact that it contains less iron and alumina than the brown rock.

In Table XI the analyses of several types of blue-rock phosphate are given, with their more prominent physical characteristics.

TABLE XI.—*Analyses of different types of Tennessee blue-rock phosphate from various localities.*

No.	Location.	Description.	Analyses.	
			P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
			Per cent.	Per cent.
40	Leatherwood Creek, Maury County..	Hard blue rock, partly weathered to rusty brown.	31.30	68.58
54	Blue Book mines, 6 miles southeast of Centerville.	Hard, close-grained blue rock.....	32.21	70.30
56	.....do.....	Hard, close-grained blue rock (high grade).	36.79	80.41
58	.....do.....	Coarse, gray oolitic rock, yet not as hard as No. 58.	31.66	69.19
59	.....do.....	Kidney phosphate, occurring in slate above blue-rock phosphate.	33.86	73.99
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	Coarse, oolitic gray rock, overlying blue rock.	25.25	55.18
61	.....do.....	Hard blue rock, underlying No. 60....	32.95	72.01
71	Meridian Fertilizer Factory, 2 miles south of Centerville.	Coarse, oolitic blue rock (unweathered).	26.44	57.79
73	.....do.....	Coarse, oolitic, blue rock (weathered) overlying high-grade blue rock.	28.82	62.98
72	.....do.....	Fine-grained, hard blue rock (sampled in tunnel).	36.66	80.11
74	.....do.....	Fine-grained, hard blue rock (sampled outside tunnel).	35.75	78.12
123	Mayfield mine, Gordonsburg, Lewis County.	Kidney phosphate, embedded in slate roof.	27.58	60.27
124	.....do.....	Fine-grained hard blue rock (high grade).	36.20	79.11

#### METHODS OF MINING.

The blue-rock phosphate is mined by first stripping around the face of the hill, then drifting in on the stratum as the overburden becomes too heavy to remove. The blue shale or slate directly overlying the phosphate forms, as a rule, an excellent roof, requiring no great amount of timbering for its support. Owing to its hardness, the rock is loosened by blasting and then broken up with picks. Compressed-air drills are now largely used in mining. The material is loaded into tramcars and wheeled or drawn by mules to the drying and crushing plant, where it is prepared for shipment. No washing is necessary for the bedded blue-rock phosphate. In Plate IV, figure 1, is shown the method of mining blue-rock phosphate.

The rock is dried both in kilns and in mechanical dryers, such as described under brown-rock phosphate. As it comes from the mines the rock contains a rather low percentage of moisture, and some of the miners deem it unnecessary to dry it at all. Since it contains both carbonate of lime and organic matter, the burning or drying process serves to increase the percentage of phosphoric acid in the finished product.

#### COST OF PRODUCTION.

In comparing the cost of mining blue-rock phosphate with that of brown there are a number of factors to be considered. Tunneling

is more expensive than mining by open cut, except where the overburden is very heavy or composed of a hard rock like that usually overlying the Devonian phosphate.

The blue rock must be blasted or drilled out, whereas the brown-rock phosphate can be removed with pick and shovel. The blue rock does not have to be washed and contains but little moisture, while much of the brown rock (as mined to-day) must be put through an elaborate cleansing process, during which considerable foreign material is handled for each ton of phosphate produced. In addition, a large quantity of fuel must be consumed to remove the water. Formerly the cost of mining blue rock was greater than that of mining brown, but the expense at present is nearly the same, approximately \$2.50 per ton.

One point in favor of blue-rock mining is that work can go on in the tunnels during wet weather, while the brown-rock mines are forced to suspend work.

#### DISPOSAL OF PRODUCT.

Although some specimens of blue-rock phosphate will run as high as 78 to 80 per cent of bone phosphate of lime, which is the grade demanded for export, the average grade of the rock is not usually more than 70 to 72 per cent. Most of the blue-rock phosphate mined in Tennessee is consumed in this county in the manufacture of acid phosphate.

#### FREIGHT RATES.

Since much of the blue rock is found in the same localities as the brown, the freight rates given on page 55 also apply to this product.

#### EXTENT OF OPERATIONS.

Extensive development work in the blue-rock region has been done along Swan Creek and its tributaries in Hickman County, along Leatherwood Creek in Maury County, and at Gordonsburg in Lewis County, but only at the latter place is much mining going on at present.

According to Van Horn,<sup>1</sup> the total quantity of blue-rock phosphate produced from 1905 to 1910 is 333,921 tons.<sup>2</sup> The annual output is given in Table IX.

#### PRESENT CONDITION OF THE INDUSTRY.

Five companies are mining blue-rock phosphate at the present time, but only one of these has a large annual output. The production of this class of phosphate is falling off considerably. This is due to a number of causes: First, many of the deposits are of an uncertain character. Sometimes the phosphate stratum thins out to almost nothing when followed into the hills, while in other localities the beds may grow thicker but become so poor in phosphoric acid that the rock is of little commercial value. Second, the enormous development of the Florida pebble phosphate fields during the last few years has caused a decline through competition. Third, new meth-

<sup>1</sup> Production of Phosphate Rock in 1910. Mineral Resources, U. S. Geological Survey.

<sup>2</sup> This includes a small tonnage from Arkansas.

ods of handling the disintegrated brown-rock phosphate, formerly considered waste, have caused a revival in these fields at the expense of the blue-rock industry.

#### FUTURE OPERATIONS.

With the exception of the high-grade blue-rock deposits and those beds which rest directly on the brown rock, so that both can be worked together, the blue phosphate will probably not be extensively mined for a number of years. The operators have so often been deceived in what promised to be extensive high-grade, blue-rock deposits, but which subsequently "pinched out," that they prefer to await better prices before undertaking to mine strata of uncertain composition. Should the price of phosphate advance, it will doubtless cause renewed activity in these fields.

#### WHITE-ROCK PHOSPHATE.

##### LOCATION OF DEPOSITS.

The white phosphate rock of Tennessee so far exploited occurs in Perry and Decatur Counties.

In the former county<sup>1</sup> the mines are located at Toms Creek, from 5 to 6 miles east of the Tennessee River. In Decatur County<sup>2</sup> the phosphate has been developed along the tributaries of Beech River, between Parsons and Decaturville. The mines are from 6 to 8 miles west of the Tennessee River and from 3 to 4 miles from the Nashville, Chattanooga & St. Louis Railroad at Parsons, Tenn. There is a good wagon road between Parsons and Decaturville.

Although the deposits of white phosphate occur mostly in pockets and can not be expected to have any great lateral extent, some of more or less importance have been reported at several widely separated localities in Perry and Decatur Counties.

##### GEOLOGICAL OCCURRENCE AND ORIGIN.

The white phosphates are all of secondary origin and belong to a much more recent geologic period than the Silurian and Devonian rocks with which they are associated. Hayes<sup>3</sup> divides them into three classes, namely, the stony, breccia, and lamellar phosphate. The first two classes, though widely disseminated, are in quantities too small and too thoroughly mixed with chert and foreign matter to be profitably mined. Fortunately, the lamellar phosphate is not only the richest, but the most plentiful of the three varieties. It is seldom found as an outcrop, but is encountered as the beds are followed into the hills. According to Hayes, it was deposited from solution in caverns in the upper Silurian limestone, the character of the rock indicating that the deposition frequently took place under hydrostatic pressure. As the limestones above these caverns were gradually dissolved by percolating and running water, the overlying

<sup>1</sup> Hayes, Ann. Report, U. S. Geological Survey, Part III, 1899-1910.

<sup>2</sup> B. Eckel, Bul. 213, U. S. Geological Survey, 418-419 (1903).

<sup>3</sup> Mineral Resources, Part 4, 623-630, 1894-95; Ann. Report U. S. Geological Survey, 1899-1900, Part III, 484-485; Ann. Report U. S. Geological Survey, 1895-96, Part II, 238-250.



strata settled down on the phosphate beds, causing a breaking up of the phosphate layers and more or less mixing with the chert fragments and residual clays from the overlying formations.

The phosphate is usually overlain by 3 to 8 feet of blue or yellow clay carrying phosphate fragments, which in turn is overlain by several feet of red and yellow clay containing limestone boulders and fragments of chert.

#### PHYSICAL PROPERTIES.

Much of the white phosphate of Tennessee resembles the hard-rock phosphate of Florida. The breccia variety consists of chert fragments embedded in a matrix of high-grade phosphate, while the stony phosphate consists of siliceous skeletons formerly filled with carbonate of lime, but now containing phosphate. Both of these grades, unless they are separated from the associated chert, are too low in phosphoric acid to be of much importance.

The lamellar variety is very high grade material. It occurs in plates of various thicknesses, which are frequently cemented together, forming large boulders weighing many tons. These plates vary from white or cream colored to pink and deep red. Some of the layers are rather porous, but the rock as a whole is close grained, very hard, and frequently coated with a thin, lustrous layer of precipitated phosphate. Picked samples of the lamellar phosphate will run as high as 85 to 90 per cent bone phosphate of lime, and there is little difficulty in obtaining rock in carload lots which will grade from 72 to 78 per cent.

A number of different types of white phosphate were collected when the author visited these fields early in 1911, but unfortunately through some mistake the various types were mixed and analyzed as one sample. Some of the samples contained large quantities of chert, so that the analysis of the whole, though given below (No. 82), is of little value. Some other phosphate analyses of the Tennessee white rock from Perry and Decatur Counties are given which show that much of this material is of excellent quality and well suited for the manufacture of superphosphate.

#### METHODS OF MINING.

The Tennessee white phosphate has been mined by both open cut and by tunneling. The former method has been employed wherever the character and depth of overburden permit, but the overload is frequently so heavy as to render its removal impracticable, and under such circumstances tunneling is resorted to. Owing to the loose character of the overlying clay, extensive timbering is required in the tunnels and much of the white phosphate embedded in the clay above can not be economically recovered.

As the phosphate is extremely hard and often occurs in very large boulders, it is usually loosened by blasting, broken up with picks, and then loaded into tramcars and sent to the plant to be crushed into pieces of uniform size.

The objectionable features of tunnel mining and hardness of the rock are largely offset by the fact that it is unnecessary either to wash or dry the white phosphate to obtain a product grading from 72 to 75 per cent of bone phosphate of lime. The results of analyses are given in Table XII.

TABLE XII.—*Analyses of samples of Tennessee white-rock phosphate.*

No.	Location.	Description.	Analyst.	Analysis.			
				SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
82	Toms Creek, Perry County.	Phosphate and chert....	C. C. Stark....	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
85	.....do.....	Phosphate from storage bins.....	.....do.....	6.55	2.71	26.77	58.49
86	Beech River Phosphate Co., Decatur County.	High-grade lamellar phosphate.	.....do.....	7.56	3.48	32.76	71.00
87	Bowlder washed out of limestone cavern on Beech River, Decatur County.	Cherty white phosphate.	.....do.....	47.00	3.90	34.49	75.36
	Perry County.....	Picked sample.....	L. P. Brown.....		1.38	18.61	40.66
	.....do.....	Sample of shipment.....	.....do.....		2.57	37.89	82.74
	Decatur County.....	Average of three small shipments.	.....do.....		2.90	35.32	77.14
						33.88	73.89

## COST OF PRODUCTION.

On account of the uncertain character of these deposits and the varying factors influencing the class of mining employed, it is difficult to estimate the average cost of preparing the white phosphate for market. Moreover, no mining has been done in these fields for several years, during which time both labor conditions and mining methods have changed.

Brown<sup>1</sup> states that the average cost of production should be slightly below that of Florida hard-rock phosphate. Considering the various factors enumerated above, it is probable that the cost of preparing the white rock for the market is somewhat higher than that of the Tennessee blue rock.

## WASTE MATERIAL.

The clay associated with and directly overlying the lamellar phosphate frequently contains many small fragments of high-grade rock. In the tunnel method of mining this phosphate is lost. Even when mining with open cut much of this phosphatic material is wasted, since the plants are not equipped for separating the good rock from the clay matrix.

The breccia and stony varieties of white phosphate have not heretofore been considered worth mining. Their low content of phosphoric acid is mainly due to the large quantity of silica or chert with which they are associated.

Hayes<sup>2</sup> suggests that the breccia variety might be utilized by crushing and subsequently screening out the chert. It is possible that the stony variety could be handled in the same way. Another method of raising the grade of these two classes of white phosphate would be to grind the rock and then put it through a washing process similar to that employed in the brown-rock fields. It is very doubtful, however, if these varieties exist in sufficient quantities at any one place to justify the installation of expensive machinery.

<sup>1</sup> Engineering Association of the South, Transactions, 15, 123 (1904).

<sup>2</sup> Mineral Resources, 4, Part IV, 625-626 (1894-95).

**EXTENT OF OPERATIONS.**

Mining operations have been carried on in but two localities in the white-rock fields, namely, at the junction of Welsdorf Branch with Toms Creek, Perry County, about 5 miles east of the Tennessee River, and on Beech River, between Parsons and Decaturville, Decatur County, 6 to 8 miles west of the Tennessee River. The plants at these two places have not been operated for several years and will need considerable repairing before work can be renewed.

The total quantity of white phosphate marketed, according to Van Horn,<sup>1</sup> is about 8,600 tons. The annual output from 1905 to 1909 is given in Table IX.

**PRESENT CONDITION OF THE INDUSTRY.**

No work has been done in the white-rock fields since 1909. The uncertain character of the deposits, the expense of mining, and the inaccessibility of many of the deposits has discouraged both prospecting and development work. When the author visited these regions early in 1911 plans were under way to renew mining operations. The property of the Perry Phosphate Co. has been taken over by a new concern, a right of way has been secured to the Tennessee River, and several acres along the river front leased with a view to shipping the rock down this stream to Paducah, Ky.

Some New York capitalists are prospecting the property of the Beech River Phosphate Co. in Decatur County, and, if indications are favorable, expect to mine the phosphate on the west side of the Tennessee River.

**FUTURE OPERATIONS.**

Thorough prospecting is necessary to determine the value and extent of the white-rock phosphate deposits. Although several areas known to contain good rock are practically untouched, a systematic prospect of these will prove quite expensive. It is doubtful if the development of this class of rock will advance very rapidly as long as large, accessible, and more uniform beds of high-grade brown-rock and blue-rock phosphate remain available.

**NATURAL PHOSPHATES OF KENTUCKY.****DESCRIPTION OF DEPOSITS.**

Within the last few years considerable interest has been manifested in the phosphate deposits of Kentucky, but conflicting rumors concerning the value of these fields have confused the prospective investor and discouraged mining development. Mention was first made of the phosphatic nature of certain strata in Kentucky by Robert Peter<sup>2</sup> in 1877. This author described a thin layer of highly phosphatic limestone occurring in the "Lower Silurian" (Ordovician) near Lexington. These layers were regarded as of too irregular distribution among the poorer limestones to be of any great commercial value.

<sup>1</sup> Production of Phosphate Rock in 1909. Mineral Resources, U. S. Geological Survey.

<sup>2</sup> Kentucky Geological Survey; chemical analysis A, 1877.

## LOCATION OF DEPOSITS.

No importance was attached to these fields until the summer of 1905, when a negro formerly employed in the phosphate mines of Mount Pleasant, Tenn., discovered a deposit of similar nature while digging post holes on the farm of H. L. Martin, near Midway, Ky. He showed the material to Mr. Martin and Mr. A. W. Davis, both of whom were familiar with the Tennessee phosphate, and who recognized the value of the discovery. Since that time prospecting has been carried on intermittently at various points in Fayette, Woodford, Scott, and Jessamine Counties, but no satisfactory and unbiased report on these deposits have as yet been published. (See fig. 2.)

Unfortunately, many of the prospect pits have been filled in and the natural exposures are few, although plans are under way for starting development work.

The phosphate area so far examined lies in Woodford, Fayette, Scott, and Jessamine Counties, but the most thoroughly prospected properties lie in Woodford County, in the vicinity of the little town of Midway. Here a number of pits and prospect holes have been dug and deposits of considerable value discovered. The phosphate area is certainly of wider extent than is generally believed, and though the material obtained from some localities does not appear to be of much economic importance, more thorough examination will no doubt lead to the discovery of other valuable deposits.

In Table XIII are given the analyses of samples of Kentucky phosphate from various localities. It must be understood that these samples are selected and do not in any case represent the average of that locality.

TABLE XIII.—*Samples of high-grade Kentucky phosphate from various localities.*

No.	Location.	Description.	Analysis.	
			P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
			Per cent.	Per cent.
110	Farm of M. D. Steel, 2½ miles south of Midway, Ky.	Hard, brown plates.....	34.02	74.36
112	Cogar farm, ½ mile south of Midway, Ky....	Thin, soft plates.....	33.75	73.74
115	Slack's farm, 3 miles northwest of Midway, Ky.	Hard, brown, heavy plates....	37.10	81.06
118	Outside State University grounds, Lexington, Ky.	Thin, brown, brittle plates....	26.13	57.10
125	Smith's farm, 2½ miles east of Georgetown, Ky.	Brown, medium hardness.....	27.14	59.43
128	Cut, 6 miles south of Lexington, Jessamine County, Ky.	Thin, brown plates.....	34.10	74.52

## GEOLOGICAL OCCURRENCE.

The Kentucky phosphate region forms part of the great Cincinnati anticline extending from Nashville, Tenn., in a northeasterly direction through Lexington, Ky., almost to Cincinnati. South of this city it divides into two broad domes, one culminating near Nashville and the other in Jessamine County, Ky. This latter is known as the Jessamine Dome.

Erosion has destroyed much of the domelike structure of this last section, and in cutting through the younger formations has caused numerous exposures of the underlying strata.

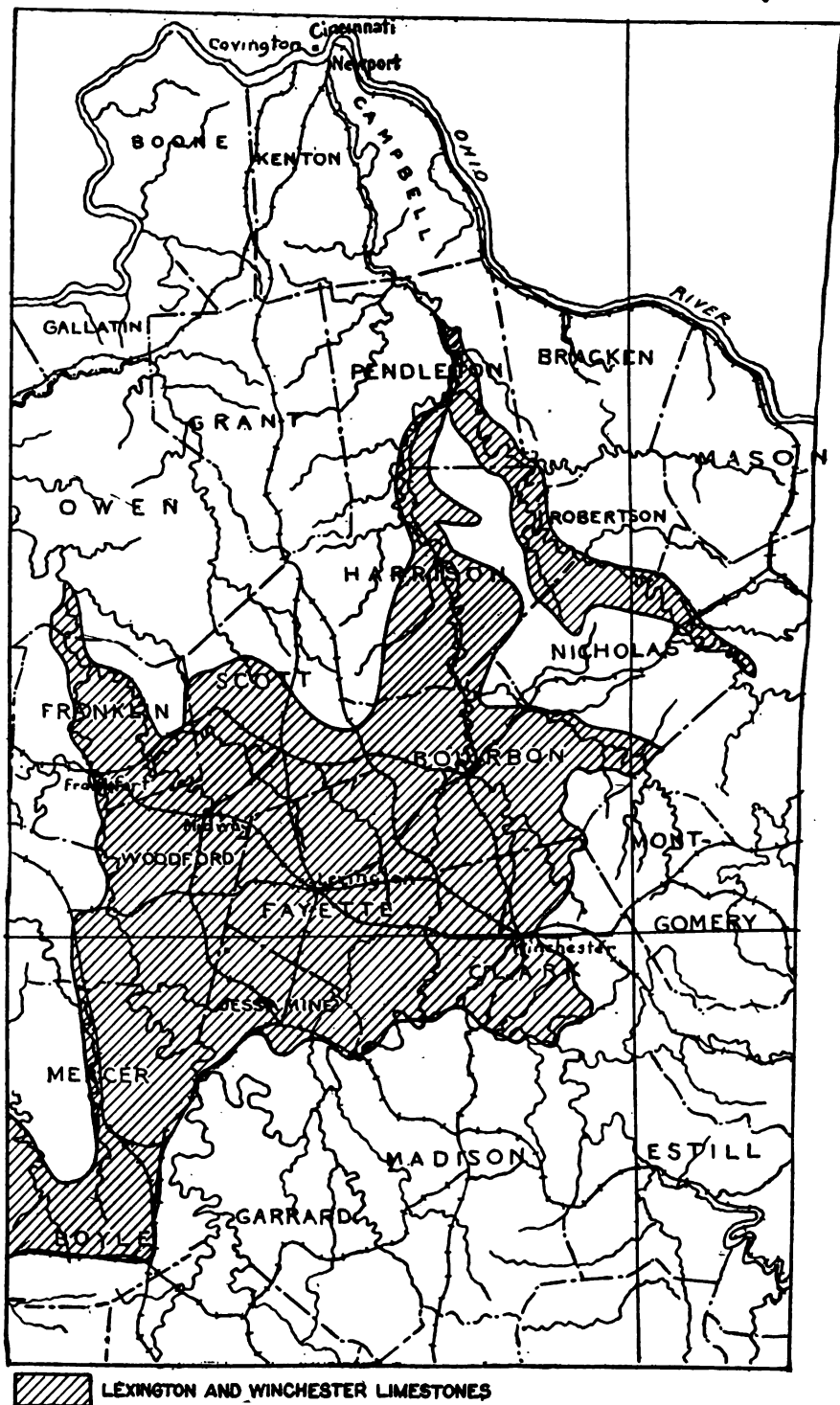


FIG. 2.—Map of the bluegrass region of Kentucky, showing distribution of the Lexington and Winchester limestones, between which the phosphate occurs.

All the exposed rocks of these regions are of sedimentary origin. The arching of the strata probably took place very gradually and has altered the horizontal position of the rocks but little. The beds rarely dip more than a few feet to the mile.

The phosphate occurs in the Ordovician ("Lower Silurian") system, at the top of the geologic formation known as the Lexington limestone.

Table XIV, taken from the report of Matson<sup>1</sup> on the "Water Resources of the Bluegrass Region, Kentucky," shows the overlying and underlying formations which are more or less related to the phosphate beds.

TABLE XIV.—Section showing phosphatic and related formations.

System.	Formation.	Description.	Thickness.
Silurian and lower part of Devonian.	Panola.....	Blue shales and yellow limestone.....	Feet. 60
	Richmond.....	(Heavy bedded, arenaceous limestone.....	60
		Blue limestone and shales.....	125
		Interbedded blue limestone and shales.....	80
	Maysville.....	Interbedded blue limestone and shales, thin and nodular; shales predominate.	230
	Eden shale.....	Shaly sandstones in southern part of region; blue shales in northern part.	200+
	Winchester limestone.....	Blue and gray limestone, with some blue shales.	60
Ordovician.....		Gray crystalline limestone, cherty (Flanagan chert member).	75
	Lexington limestone.....	(Phosphate Horizon.) Argillaceous limestone and shale and bedded blue limestone.	194
		Heavy, bedded, coarse-grained crystalline, cherty limestone, usually gray.	30
		Dense fine-grained gray limestone.....	90
	Highbridge limestone.....	Dense fine-grained dove-colored or gray limestone.	20-60
		Dense, fine-grained, dark, heavy bedded limestone.	285
	St. Peters sandstone.....	Limestone known only from well records.....	100+
		Siliceous limestone.....	

The phosphate rock occurs in thin plates embedded in a matrix of clay, siliceous material, and disintegrated phosphate, the whole having a thickness varying from a few inches to 10 or 12 feet. In some of the deposits considerable chert occurs, which may render the mining and grading of the phosphate somewhat difficult.

#### PHYSICAL PROPERTIES.

The phosphate rock itself varies somewhat in its physical properties. In color it ranges from a light gray to a rich chocolate brown and in texture from a compact, close-grained plate rock to porous cellular fragments and disintegrated phosphate.

Most of the rock is in thin, close-grained plates, brownish gray in color and fairly hard. The average apparent specific gravity is about 3.

Samples of the various types were analyzed, and the results of these analyses are given in Table XV, where the composition is compared with the predominant physical properties.

<sup>1</sup> Water Supply Paper, No. 233, United States Geological Survey. 1909.

TABLE XV.—*Composition of the different varieties of Kentucky phosphate.*

No.	Location.	Description.	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
200 K	Near Midway, Ky.	Light yellow, brown, soft....	<i>Per cent.</i> 24.29	<i>Per cent.</i> 17.18	<i>Per cent.</i> 21.34	<i>Per cent.</i> 46.71
201 K	.....do.....	Brown, chocolate, close grained, thin bedded.	2.63	2.75	35.71	78.17
202 K	.....do.....	Brown, chocolate, porous, hard.	4.88	3.67	34.00	74.43

## METHODS OF MINING.

Owing to the presence of so much finely divided foreign material in the phosphate deposits, it will be necessary to wash the phosphate rock before it can be used for the manufacture of acid phosphate. Plants for washing out the foreign material and at the same time saving the finely divided phosphate rock have proved very successful in the Tennessee phosphate fields. The method of separation is based on the difference between the specific gravities of the phosphate and the siliceous and clay matrix.

Where water is available both the overburden and phosphate might be successfully handled by the hydraulic method of mining. Since the deposits occur on the hills, the waste material could be disposed of by gravity. These methods entail considerable initial outlay, a fact that will probably militate against the small operator, as from an economic standpoint it is advisable that plants should be erected that will reduce the element of waste to a minimum.

In Table XVI the phosphate content of samples of the Kentucky phosphate before and after washing are given. The washing process, however, was not very thorough, as will be seen from the analysis.

TABLE XVI.—*Analysis of samples of Kentucky phosphate before and after washing.*

Sample No.	Location.	Depth.	Amount recovered after washing.	Analyses.					
				Before washing.			After washing.		
				SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub> Fe <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub> Fe <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>
90-100	Shallow pit, filled, farm of M. D. Steel, 2½ miles from Midway, Ky.....	<i>Ft. in.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
100-101	.....do.....	2	80.00	.....	.....	31.74	.....	.....	33.57
102-107	.....do.....	2 4	60.60	.....	.....	23.90	9.48	5.46	31.06
106-106	Deep pit on farm of M. D. Steel.....	3½	77.80	.....	.....	25.45	11.27	6.28	29.43
104-102-102	.....do.....	3 6	73.80	.....	.....	22.82	17.05	7.80	26.80
113-114	.....do.....	6 10½	76.00	.....	.....	22.85	11.95	7.55	29.28
126-127	Farm of J. Slack, 2 miles northwest of Midway, Ky.....	.....	66.70	.....	.....	19.83	.....	.....	26.16
	From cut 6 miles south of Lexington, in Jessamine County, Ky.....	8 3	36.36	.....	.....	23.70	16.01	12.84	29.29

<sup>1</sup> Contained considerable chert.

## MARKETING.

As a distributing point for the Middle West, Kentucky is much better situated than Tennessee. During the year 1910 the sales of ground rock phosphate in those regions greatly increased, and though

the average mine run of the Kentucky phosphate is probably not as high as that from the Tennessee brown-rock area, the difference in freight rates will compensate in many instances for the difference in the grade of the product.

Table XVII gives the freight rates from Midway, Ky., to towns in the Middle West as compared with those from the phosphate regions of Tennessee.

TABLE XVII.—*Freight rates from mines in Kentucky and Tennessee to important near-by markets.*

Destination.	Location of mines.	Freight rates.
Cincinnati, Ohio.....	Midway, Ky.....	\$1.57
	Mount Pleasant, Tenn.....	2.50
	Wales Station, Tenn.....	
	Nashville, Tenn.....	
Louisville, Ky.....	Midway, Ky.....	1.57
	Mount Pleasant, Tenn.....	2.00
	Wales Station, Tenn.....	
	Nashville, Tenn.....	
Cleveland, Ohio.....	Midway, Ky.....	3.72
	Mount Pleasant, Tenn.....	3.80
	Wales Station, Tenn.....	
	Nashville, Tenn.....	

#### PRESENT CONDITION OF THE INDUSTRY.

Up to the spring of 1911 work on the Kentucky phosphate area had been confined to prospecting. A small plant is now in course of construction which will start operations this year, and will probably accelerate greatly the development of the area.

The owners of phosphate lands are holding their property at high figures. This is partly due to the fact that shortly after the rock was discovered large sums were paid for options on several farms in the vicinity of Midway. These options were renewed upon payment of other large sums, but were finally allowed to lapse, owing to lack of capital to develop the properties. The farmers therefore have a somewhat exaggerated idea of the value of their farms.

Recently there were 2,400 acres under option or leased by companies and individuals interested in the phosphate industry. The land under lease is to be mined on the royalty basis, 25 cents to 50 cents being paid on every ton of rock produced, with a guaranty of a certain tonnage each year.

#### OUTLOOK.

It is only a question of time before the Kentucky phosphate fields will be developed. The value of the deposits has not as yet been sufficiently well established to encourage the outlay of much capital, but the erection of the plant cited above will draw attention to this area, and it seems probable that its favorable location and the character of the output will put mining operations in the area on a sound footing.

#### NATURAL PHOSPHATES OF ARKANSAS.

##### GENERAL DESCRIPTION OF DEPOSITS.

The phosphate deposits of Arkansas are not generally regarded as of great economic importance. Compared with the product of the Tennessee and Florida fields the rock is rather low grade. The deposits are well situated to supply the growing demand for fertilizers west of the Mississippi River, and, though much of the material is too





low in phosphoric acid and too high in iron to make it desirable for the manufacture of superphosphate, the increasing consumption of ground rock phosphate for agricultural purposes will no doubt hasten further development in these fields.

The phosphate rock was not recognized as such until 1895, and it was not until 1896 that Branner<sup>1</sup> published a report on these deposits. In 1902 Branner and Newson<sup>2</sup> made a fuller geological report on these fields, embodying a large amount of analytical data and including a discussion of the transportation facilities and market for the product.

Purdue<sup>3</sup> published a short paper on the Arkansas phosphates in 1902, shortly after the plant of the Arkansas Fertilizer Co. was burned, but since that time, so far as can be learned, no publication of any note has been issued.

#### LOCATION OF DEPOSITS.

The portion of the phosphate fields now being worked lies in the northwestern part of Independence County, along Lafferty Creek, north and east of the White River. The deposits, however, extend over a considerable area in north-central Arkansas, and the phosphate horizon has been recognized in Stone, Izard, Searcy, Marion, Baxter, and Newton Counties. (See fig. 3.)

Mention has also been made of the occurrence of phosphate nodules in Clark County at a different geological horizon, but the pebbles have never been found in sufficient quantities to prove of economic interest.

Some of the samples from other sources have analyzed very much higher than those from the deposits along Lafferty Creek, but transportation facilities are poor or, upon further investigation, the material has been found to be limited in quantity. This is the objection to the deposits found in Hickory Valley, where samples have been collected which ran over 73 per cent of  $\text{Ca}_3(\text{PO}_4)_2$ .

The analyses given in Table XVIII, taken from the report of Branner and Newson,<sup>4</sup> give some idea of the character and richness of the phosphate rock from other localities.

TABLE XVIII.—*Analyses of Arkansas phosphates.*

Location.	Thickness and character of beds.	Analyses.	
		$\text{Ca}_3(\text{PO}_4)_2$	$\text{Fe}_2\text{O}_3\text{Al}_2\text{O}_3$
		Per cent.	Per cent.
Miligan place, 12 miles northeast of Batesville (T. 14 N., R. 5 W., sec. 6).	5 feet.....	47.19	.....
Do.....	Washed pebbles.....	73.76	3.82
Do.....	Not determined.....	57.03	5.89
Do.....	do.....	64.17	3.08
Do.....	Boulders.....	67.79	3.01
Do.....	Fragments.....	73.20	5.19
Do.....	Not determined.....	62.08	2.97
Meeker place, $\frac{1}{2}$ mile west of Coahman (T. 14 N., R. 7 W., sec. 8).	2 feet 6 inches.....	49.38	8.82
Meeker place, $\frac{1}{2}$ mile west of Coahman (T. 14 N., R. 8 W., sec. 12).	2 feet.....	58.31	5.85
Meeker place, $\frac{1}{2}$ mile west of Coahman (T. 14 N., R. 8 W., sec. 14).	1 foot 6 inches.....	68.72	8.81
Tate's field (T. 14 N., R. 8 W., sec. 4).....	1 foot.....	66.39	4.18
Keating's place (T. 16 N., R. 18 W., sec. 18).....	4 feet (reported).....	78.62	7.21
Meekery Run, near St. Joe, Searcy County.....	Nodules (black).....	69.31	8.10
Do.....	Nodules (brown).....	56.58	9.01

<sup>1</sup> Amer. Inst. Min. Eng., 26, 1896.

<sup>2</sup> Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

<sup>3</sup> Bul. 815, U. S. Geological Survey, 463-473 (1907).

<sup>4</sup> Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

## GEOLOGICAL OCCURRENCE.

The exposed rocks in Northern Arkansas are all of sedimentary origin, the strata lying almost horizontally. The commercially important deposits of phosphate were formerly considered of Devonian age,<sup>1</sup> but more recent investigations have shown that they are older, but that they are not younger than the Silurian period.<sup>2</sup> The Cason shale, in which they occur, is of Ordovician age. The following summary, taken from the report of Purdue, shows a general section, with the formations more or less related to the phosphate beds:

Carboniferous.....	Boone chert, including St. Joe marble.
Devonian.....	Chattanooga shale and Sylamore sandstone.
Silurian.....	St. Clair limestone.
Ordovician.....	{ Cason shale (phosphate horizon). Polk Bayou limestone. Izard limestone.

As will be seen from inspection of the above table, the phosphate occurs between two limestone formations, both of which are characteristic and hence form excellent guides to the phosphate horizon. The overlying or St. Clair limestone in the vicinity of the developed phosphate deposits varies from 6 to 10 feet in thickness. It is a medium-grained, crystalline limestone, pinkish white in color, containing characteristic fossils, which stand out prominently on weathered surfaces.

The Polk Bayou limestone, the underlying formation, varies considerably in thickness, ranging from 75 to 130 feet. It occurs in massive beds and varies in color from light gray to chocolate brown. Its texture is very coarse, the rock being made up of fossil fragments cemented together with crystals of calcite. This limestone rests directly upon the Izard limestone, which consists of a very close-grained limestone, almost fine enough to be used as lithographing stones. In some localities the Izard attains a considerable thickness.

The rocks of the phosphate horizon vary considerably in character, but there are always bands of shale occurring among the phosphate strata. Manganese ore is also closely associated with the phosphate in many places, much of the rock being stained by this substance. The finding of manganese ore has often led to the location of the phosphate.

Branner<sup>3</sup> states that the Arkansas phosphate is derived from the droppings and remains of fish and other marine agencies laid down gradually in deep water. Clark<sup>4</sup> is of the opinion that these deposits were formed in a similar manner to those of Tennessee, i. e., laid down in a shallow sea as phosphatic limestones and subsequently enriched by mechanical and chemical processes. Purdue<sup>5</sup> concludes, from the conglomerate character of the rock, that the deposition of the phosphate beds took place in shallow water, having closely followed the shore line as it advanced inland. The presence of large quantities of organic fragments indicate, in the opinion of this authority, that the deposits are the result of wave action.

<sup>1</sup> Branner, Amer. Inst. of Min. Eng., 26, 1896; Branner and Newson, Bul. 74, Ark. Agr. Expt. Sta., 1903.

<sup>2</sup> Purdue, Bul. 315, U. S. Geological Survey, 463-473 (1907).

<sup>3</sup> Amer. Inst. Min. Eng., 26, 1896.

<sup>4</sup> Data of Geochemistry.

<sup>5</sup> Bul. 310, U. S. Geological Survey, 471-472 (1907).

Taking into consideration the close-grained character of the phosphate rock, it is unlikely that there has been any enrichment brought about by the leaching out of carbonate of lime subsequent to the final deposition of the phosphate strata.

The following sections (Table XIX), sampled at two different localities, show the nature and phosphoric-acid content of the various phosphate strata:

TABLE XIX.—Analyses and description of phosphate strata from different localities.

Sample No.	Location.	Thickness of strata.	Description.	Analysis.	
				P <sub>2</sub> O <sub>5</sub>	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>
		<i>Feet.</i>		<i>Per cent.</i>	<i>Per cent.</i>
	"Phosphate," 12 miles northwest of Batesville.	2.5	Ferruginous limestone (roof).....	Trace.	Trace.
92	.....do.....	.5	Green shale (weathers to powder) ....	5.82	12.72
80	.....do.....	4.0	Hard, gray, nodular.....	28.85	63.05
81	.....do.....	2.0	Hard, gray, less nodular.....	14.16	30.94
97	1½ miles north of Phosphate.	1.5	Ferruginous phosphate.....	19.60	42.94
	.....do.....	.5	Thin-bedded shale (not sampled).....		
96	.....do.....	3.0	Hard, gray oolitic phosphate.....	22.96	50.18
95	.....do.....	1.0	Hard, gray oolitic phosphate, low grade.	10.01	21.87
98	.....do.....	Undetermined.	Ferruginous shale.....	7.53	16.45

#### PHYSICAL PROPERTIES.

The phosphate in the developed area occurs in two strata, one directly overlying the other. The first or upper layer is from 3½ to 6 feet in thickness and consists of a hard, massive rock made up of rounded fragments of organic debris closely cemented together. Its specific gravity is about 3. It varies in color from light gray to brownish black, the color depending largely on the content of iron and manganese. This is the bed considered worth mining.

Directly under this bed lies another stratum of phosphate rock from 2 to 4 feet in thickness and closely resembling that just described. It is, however, less oolitic and contains appreciably less phosphoric acid. This stratum is discarded in mining.

Table XX gives the analyses of typical samples of Arkansas phosphate, together with the more prominent physical characteristics of the rock.

TABLE XX.—Analyses of typical samples of Arkansas phosphate.

No.	Location.	Thickness.	Description.	Analysis.		
				SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub> -Al <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>
		<i>Feet.</i>		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
96	1½ miles north of Phosphate..	3	Hard, gray oolitic.....	39.94	7.00	22.96
96	.....do.....	1	Hard, brownish black, low grade.	58.25	2.43	10.01
92	"Phosphate," Arkansas Fertilizer Co., east side of creek.	6	Hard, grayish brown, oolitic, high grade.	24.31	9.33	24.80
91	"Phosphate," West side of creek, Arkansas Fertilizer Co.	2	Hard, gray, low grade.....	24.94	7.43	14.16

## METHODS OF MINING.

The Arkansas phosphate is mined in the same way as the blue-rock phosphate of Tennessee, by first stripping around the face of the hill till the overburden becomes too heavy to be profitably removed. Drifts are then run into the hillside and the rock blasted out. From the tunnel mouth it is loaded for shipment or piled upon ricks of wood and burned, the latter process being favored at the mines, as fuel is abundant and burning reduces freight charges by expelling most of the moisture from the rock.

It is claimed by the fertilizer manufacturer that burning the rock also facilitates crushing, since the ovules, which are usually the richest part of the phosphate rock, are rendered brittle and can be more finely ground for the subsequent acid treatment.

## COST OF MINING.

The actual cost of mining varies considerably, depending on the accessibility and character of the deposit which is being worked. On the property of the Arkansas Fertilizer Co. most of the phosphate occurs some distance above the level of Lafferty Creek, but dips below this stream as one follows the stratum south. The extraction of material in the latter case will no doubt prove quite expensive.

Owing to the resistance of phosphate to weathering influences, the rock frequently forms a kind of bench around the hills, the overburden being largely removed by erosion for some distance back from the phosphate outcrop. Mining under these conditions can be carried on for some time by simply scraping off the light overburden or detritus and blasting or cutting out the rock thus exposed. This class of mining should be carried on at a cost not exceeding 75 cents per ton.

As the overburden gets heavier it becomes necessary to run drifts into the hillside and mine the material very much like a seam of coal. This latter method is more expensive than the open-cut system, since much waste material has to be hauled out of the tunnels and considerable timber used in supporting the roof. As the tunneling proceeds farther into the hills less timbering is usually required, as the St. Clair limestone and unweathered slate overlying the phosphate form a fairly substantial roof. The average cost per ton is rather hard to strike, but, all things considered, it is probably less than \$2.25.

## MARKETING.

All the material mined on Lafferty Creek is at present shipped to Little Rock, Ark., and either made into acid phosphate or sold directly to farmers as ground rock phosphate. The acid phosphate contains about 14 per cent of phosphoric acid.

The freight rate on phosphate rock from Batesville to Little Rock, Ark., is \$1 per ton.

## OPERATING CONDITIONS.

The phosphate stratum directly underlying the main bed is either left untouched or taken out and discarded in mining operations. It varies from 1 to 4 feet in thickness and contains an average of 30 to

40 per cent of tricalcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ . At present it would not be practicable to ship this material, since the freight rate is too high and the material of too low grade for the direct manufacture of acid phosphate.

Ground rock phosphate has not been used to any extent west of the Mississippi River, the present demand being for 62 per cent rock. This lower-grade phosphate would prove of value when ground, but the application would have to be heavy, and unless the market was within easy reach of the mines it would not be possible to dispose of the material at a profit. If the present tunnels are not allowed to collapse it will be possible to return and mine the low-grade rock when the market and improved methods of handling it shall make it profitable.

Only one company has mined Arkansas phosphate to any extent. In sec. 14, T. 14, R. 8 W, 12 miles northwest of Batesville, near the junction of East and West Lafferty Creeks, the phosphate has been opened up by nine tunnels run into the hill on the west side of the creek. Numerous rooms branch out from these main tunnels, and fully 50,000 tons of rock have been taken out. The stratum of high-grade phosphate here has an average thickness of  $3\frac{1}{2}$  to 4 feet.

As the phosphate is traced southward on the west side of the creek the beds dip rather sharply, and when the mines were visited in May, 1911, a shaft was being sunk below the level of the creek in order to locate the deposit.

On the east side of the creek the beds are nearly horizontal and considerably thicker, a 6-foot stratum being in evidence for one-half mile along the hillside. An analysis of an average sample of this stratum given in Table XX.

#### OUTLOOK.

There is every probability that the mining operations in the Arkansas phosphate fields will be extended. A fertilizer company of Little Rock, Ark., is preparing to enlarge an already extensive plant and is contemplating the erection of a sulphuric-acid factory. A number of other companies and individuals have large interests in these fields, and although some of them were bought primarily to develop the manganese deposits, they will no doubt handle the phosphate rock as the demand for this material increases. The fact that manganese and phosphate are so closely associated in these regions is sufficient guaranty that the deposits will be extensively worked at some future date.

W. H. WAGGAMAN.

## APPENDIX B.

### REFERENCE LIST FOR PHOSPHATES.

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## APPENDIX C.

### MEMORANDUM ON THE MANUFACTURE OF ACID PHOSPHATE IN THE SOUTHERN STATES.

#### INTRODUCTION.

The acid-phosphate industry in the Southern States has grown to enormous proportions within the past decade. In spite of the fact that numerous other soluble phosphatic fertilizers have been patented and the application of raw ground-rock phosphate directly to the field has been advocated by a number of agronomists and agricultural chemists the annual production of superphosphate continues to increase. There is little doubt, therefore, that this material will be the basis of most of the commercial fertilizers for many years.

The general procedure followed in making acid phosphate is a familiar one, but there are many details concerning its manufacture which are not generally known. It is the object of this report to outline the most modern methods practiced in the factories of our Southern States and to describe such details concerning the materials used, machinery employed, and methods of mixing and storing the superphosphate as are of economic and scientific interest.

#### RAW MATERIALS.

The raw materials used in the manufacture of acid phosphate are phosphate rock and sulphuric acid.

The phosphate rock is obtained from three sources, namely, Florida, South Carolina, and Tennessee.

During the past few years the Florida rock has almost entirely displaced the phosphate from the other two States. It is claimed that it produces a superphosphate of more uniform composition and of better mechanical condition than either of the other two types of rock. Most of the Florida phosphate used is of the pebble variety. It is sold on a guaranty of 65 to 68 bone phosphate of lime,  $\text{Ca}_2(\text{PO}_4)_2$ , with a low content of iron and alumina. A considerable quantity of "fines" obtained from screening the Florida hard-rock phosphate is also used for making acid phosphate. These "fines" are too low grade for the foreign market, but make an excellent acid phosphate. They grade from 70 to 72 per cent bone phosphate of lime.

The South Carolina rock is used principally in the Carolinas and Virginia. It is considerably lower in grade than either the Tennessee

or Florida phosphate, and is therefore little used at points equally close to the other two fields. The rock ranges from 62 to 65 per cent bone phosphate of lime, and produces an acid phosphate containing about 14 per cent of so-called available phosphoric acid. The product, however, is usually in good mechanical condition.

There exists at present in Georgia, Alabama, and the Carolinas considerable prejudice against the Tennessee phosphate. The superphosphate manufacturers claim that it produces an acid phosphate of variable composition and often in a poor mechanical condition. The trouble experienced from its use has been no doubt partly due to the fact that much of the Tennessee brown rock first put on the market was imperfectly cleansed, the foreign material contained in the interstices probably causing the product to be sticky and the soluble phosphate content to vary. A much better class of rock is now being sold, which will in time disperse the prejudice now existing against Tennessee phosphate.

The sulphuric acid used in the manufacture of acid phosphate is ordinary chamber acid ( $50^{\circ}$  to  $52^{\circ}$  Baumé), and is obtained from the acid factories which are usually run in connection with the fertilizer plants. Some of the plants, however, use the acid obtained as a by-product from the copper smelters in southeastern Tennessee. This acid is shipped in tank cars at a strength of  $60^{\circ}$  Baumé, and is diluted with water before mixing with the phosphate rock.

#### METHOD OF MANUFACTURE.

The phosphate rock is first put through a crusher and broken into pieces not larger than a walnut. This crushing is hardly necessary in the case of the Florida pebble phosphate or the screenings from the hard-rock phosphate, since the pebbles and fragments are usually small enough to be fed directly to the mill.

There are a number of different types of rock mills used in the Southern States. Some of them combine both grinding machinery and screens in one. Others discharge the partly ground material into elevators to be subsequently screened, the coarser material being returned to the mill. The latter plan seems to be more generally used in the southern fertilizer factories, and since the mills are simpler and not so apt to become clogged, they are probably more economical than the combined mill and screen.

The rock is ground so that 80 to 90 per cent will pass a 60-mesh sieve. At some of the factories it is ground even finer, 80 per cent passing through an 80-mesh screen. When the rock is not screened in the mill it is carried by elevators and passed over screens inclined at an angle of  $45^{\circ}$  to  $50^{\circ}$ , which are constantly vibrated by hammers. The mesh of these screens is considerably coarser than the material which passes through, the fineness of the rock obtained depending on the angle of inclination. The finely ground rock is then carried by elevators to the storage bin, whence it is drawn as required.

A definite weight of rock and usually an equal weight of acid are run into the mixer at the same time. The mixer consists usually of a cast-iron pan from 18 inches to 2 feet deep and having a capacity of 1 to 2 tons. The pan revolves slowly and is equipped with cast-iron or steel stirring devices. In order to facilitate the chemical

reactions the sulphuric acid is frequently used at a temperature of 130° F. In the open-dump system (described later) it is especially important that the acid be heated to a fairly high temperature, since the reactions in the mixer should start promptly.<sup>1</sup> After thoroughly stirring for two to five minutes the mixture is discharged either into the bin directly below the mixer or into a car, which takes it to the storage shed and dumps it in a pile.

Both the "den" and "open-dump" methods are employed in the southern fertilizer factories. Each of the two methods has features to recommend it. By use of the dens a product of high availability (so called) can be obtained in a short time, since much of the heat developed is conserved within the chambers and the necessary reactions take place more rapidly. The dens consist of brick or brick-lined chambers holding all the way from 150 to 300 tons of acid phosphate and are provided with doors at opposite sides, which are opened when the material is ready to be dug out. The floors of the dens are frequently constructed so that a portion can be opened and the material discharged into a hopper below, whence it is taken up by elevators and dumped on the storage pile. Both the initial cost and running expenses of the "den" system are greater than the "open-dump" method, but a high-grade superphosphate in excellent mechanical condition can be obtained in a short space of time by the former method.

In the "open-dump" method the phosphoric acid takes considerably longer to reach its maximum availability, and unless the mixing has been done carefully the superphosphate may never reach the desired mechanical condition. On the other hand, by careful work and where it is unnecessary to ship the material immediately, a product can be obtained equal to that obtained by the "den" system and at a lower cost.

At one of the southern plants a partly open bin is employed for holding the freshly made acid phosphate. The sides of the bin prevent the material from spreading to such an extent as to lose its heat. After allowing the material to stand for 8 or 10 days, it is raised by elevators and dumped on a storage pile.

#### STORING THE ACID PHOSPHATE.

In order that the superphosphate produced may contain a maximum quantity of readily soluble phosphoric acid when ready for shipment, it is usually stored in a pile for at least two weeks. During this time the quantity of so-called available phosphoric acid constantly increases. This is especially true of the superphosphate made by the open-dump method, where the heat is not sufficiently great to bring about rapid reactions.

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<sup>1</sup> Porter, F. B. Jour. Ind. and Eng. Chem., 3, 108 (1911).

In the following table are given the analyses of two piles of acid phosphate sampled after standing certain definite periods of time:

TABLE I.—*Analysis of acid phosphate made by open-dump method after standing from 13 hours to 6 months.*

Time of storage.	Available phosphoric acid.	Insoluble phosphoric acid.	Moisture.
No. 1:	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
3 days.....	15.70	2.06	12.80
10 days.....	16.63	1.02	12.70
6 months.....	16.93	.47	13.80
No. 2:			
13 hours.....	15.55	1.50	.....
3 days.....	15.70	1.80	12.60
6 months.....	17.19	.18	13.94

Although the so-called available phosphoric acid continues to increase after storing for some time, the moisture content also frequently increases, so it is doubtful whether it is desirable to keep the material for any great length of time except in a very dry atmosphere.

#### COST OF PRODUCTION.

The cost of producing acid phosphate depends on a number of factors, which vary between rather wide limits. These are the size, location, and equipment of the plant and the cost of the sulphuric acid employed in the process.

The use of rock mills which will grind the largest quantity of rock with the least expenditure of time and power, and the employment of mixers having a capacity of 2 tons instead of 1 ton, tend to reduce the cost of acid phosphate per ton. Plants located at seaports, where the cost of manufacturing sulphuric acid is less and the price of Florida rock usually lower, can often produce acid phosphate cheaper than those located at inland points. On the other hand, factories located at inland points which are within easy access of the phosphate fields can obtain their phosphate rock cheaper than those more distant from the source of supply. Again, those plants which have their own acid factories can manufacture sulphuric acid cheaper than it can be bought by companies which do not make their own acid.

The initial cost of producing acid phosphate by the den system is greater than by the open-dump method, but since the material can be shipped much sooner when made by the former method less interest is lost on the money invested.

At inland points such as Atlanta, Augusta, and Birmingham the cost of producing acid phosphate (16 per cent citrate soluble), exclusive of office expenses, varies from \$6.75 to \$8 per ton. At seaports such as Charleston, Savannah, Baltimore, and Norfolk the cost ranges from \$6.20 to \$7.50 per ton.

The following itemized statement gives the cost of producing acid phosphate at a plant running under good conditions located at a seaport and using Florida phosphates:

*Average cost per ton (2,000 pounds) of acid phosphate at plant located at seaport and running at full capacity of 500 tons per week on the den system.*

Phosphate rock (1,133 pounds), at \$5.09 per ton.....	\$2.576
Sulphuric acid (1,080 pounds), at \$4.75 per ton.....	2.585
Direct labor .....	.264
Five-eighths superintendent's salary.....	.091
Power, oil, and waste.....	.232
Insurance on \$60,000 at 1.55 per cent.....	.035
Taxes on \$75,000 at 1.25 per cent.....	.036
Depreciation on \$60,000 at 10 per cent.....	.231
Interest on \$75,000 at 6 per cent.....	.173
Total cost per ton.....	6.203

W. H. WAGGAMAN.



## APPENDIX D.

### MEMORANDUM ON THE MANUFACTURE OF SULPHURIC ACID.

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#### INTRODUCTION.

The basis of nearly all commercial fertilizers is soluble phosphoric acid. Since phosphoric acid is usually obtained in this condition by the action of sulphuric acid on various phosphatic substances, the manufacture of this latter acid is very closely allied with the fertilizer industry. Almost every fertilizer plant (excepting the cottonseed meal factories) with an annual capacity of 15,000 tons or more has, in connection with it, a sulphuric-acid plant. In Georgia alone the annual production of sulphuric acid for the fertilizer trade is over 260,000 tons, and besides this considerable acid is shipped into the State from the smelters in southeastern Tennessee.

The manufacture of sulphuric acid has been described by numerous authors, notably Lunge, Gilchrist, Thorpe, Falding, Sorel, Raschige, Hurter, and Schertel.

Lunge, particularly, has entered into great detail concerning the materials used, the construction of the chambers, labor required, yield of acid, and cost of production.

The method of manufacture to-day is essentially the same as it was at the time these authors wrote upon the subject; but in view of the fact that a few years bring about great changes in labor conditions and cost of materials and that certain companies have introduced new details into their acid factories, it is thought desirable to outline the general method of procedure followed in the Southern and Eastern States, to describe such innovations as affect the cost of production and yield of acid, and to discuss other details of scientific and economic interest.

The sulphuric acid for the fertilizer trade is practically all produced by the lead-chamber method. The contact process for making strong sulphuric acid or oil of vitriol is employed at several chemical works in this country, but little or none of this acid is used in making superphosphate, since it is somewhat more expensive and unnecessarily pure for fertilizer purposes. A plant manufacturing acid by this process requires very close supervision by a well-trained chemist and superintendent.

Although acid of 50° Baumé, the strength required for making acid phosphate, can no doubt be made more cheaply by the chamber process, there are numerous plants which are in such bad repair or run so inefficiently that the cost of acid per ton, of the above strength, is considerably higher than the cost of that made at some of the contact plants. Strong acid can be made more cheaply at a

well-run plant employing a contact process, since it requires no concentrating by evaporation in expensive platinum vessels.

In this report only the chamber process is described.

#### RAW MATERIALS.

The raw materials required for the manufacture of sulphuric acid are pyrites, or crude sulphur, and saltpeter or nitric acid.

In the South pyrites are used almost entirely. The lump ore is obtained chiefly from Spain and contains from 48 to 52 per cent of sulphur. It is sold on the long-ton basis and is worth f. o. b. at the ports 12½ to 13 cents per unit.<sup>1</sup> The domestic ore is obtained from Virginia, Georgia, and Tennessee. Much of it is in the form of "fines" and has to be burnt in a special furnace described below.

The oxides of nitrogen required in the chamber process are derived from either sodium nitrate or nitric acid. Chile saltpeter is used almost entirely at the southern acid factories. It costs at the ports about \$44 per ton of 2,000 pounds.

#### METHOD OF MANUFACTURE.

The lead-chamber process for manufacturing sulphuric acid is based on the union of sulphur dioxide ( $\text{SO}_2$ ) with the oxygen of the air to form sulphur trioxide. This union is brought about by the catalytic action of the higher oxides of nitrogen and takes place in the presence of water vapor. The water present combines with sulphur trioxide to form sulphuric acid, thus setting free the oxides of nitrogen to act upon fresh gases.

If lump ore is used the pyrites are burned in brick furnaces having a grate composed of single square bars, which can be turned upon their longitudinal axes in order to let the cinders down into the ash pit. The furnaces hold from 3 to 5 tons each and are arranged in batteries of 20 to 25 for each set of lead chambers. Each furnace is charged with from 750 to 1,000 pounds of ore every 24 hours. The burners for the pyrites "fines" has a series of shelves so arranged that the burning material can be mechanically raked from one shelf to another. This insures perfect combustion and prevents clinkers from forming in the furnace. The rakes are attached to a central water-cooled shaft. The mechanical or rotary furnaces vary in capacity from 2,400 pounds to 40,000 pounds of pyrites per day (24 hours). The two types employed in the South are the Herreshoff and the Wedge burners.

The gases from the pyrites burners are forced into a dust chamber or flue, fitted with baffles to hasten the deposition of the finely divided pyrites, and the oxides of iron, zinc, arsenic, and antimony carried over by the draft. It is highly important that most of these oxides be removed from the burner gases before they enter the system, since the dust not only contaminates the acid but clogs and cuts down the efficiency of the Glover tower. The dust chambers are frequently constructed so that a portion may be shut off and cleansed without interfering with the operation of the furnaces.

<sup>1</sup> A unit is 1 per cent, or 22.4 pounds, of sulphur to a long ton.

The oxides of nitrogen are either introduced into the flue by the action of sulphuric acid upon sodium nitrate or sprayed into the system in the form of nitric acid or sometimes as a solution of sodium nitrate in water. The first of these methods is used almost entirely at the sulphuric-acid plants in the South and East, but the use of nitric acid has much to recommend it.

The mixture of gases is led from the flue into the Glover tower, which consists of a lead tower (usually from 20 to 30 feet in height and 6 to 8 feet across) lined with acid-resisting brick and partly filled with quartz or vitrified brick. At the top of the tower is an apparatus for distributing dilute nitrous vitriol (brought from the Gay Lussac tower), which trickles through the Glover tower. The heat from the burner gases drives off both water and the oxides of nitrogen from this dilute acid.

The uses of the Glover tower, therefore, are threefold: First, to cool the hot gases from the pyrites burners; second, to reintroduce water and the oxides of nitrogen into the system; and, third, to produce an acid more concentrated than that formed in the lead chambers.

From the Glover tower the gases pass into the first of the lead chambers where most of the sulphuric acid is made. The chambers are usually large, square or oblong boxes made of sheet lead (weighing from 6 to 8 pounds to the square foot) and having a capacity of 25,000 to 75,000 cubic feet each.

The old method of constructing chambers—and, indeed, it is still largely practiced—is to suspend the chamber like a huge bottomless box over a lead pan from 1.5 to 2 feet deep in such a way that the lower ends of the chamber walls dip deep into the pan. The acid formed in the pan acts as a seal, preventing the escape of the chamber gases. Many chambers are now constructed in one section, the lower end of the chamber walls being sealed directly to the upper edge of the acid pan. This method has the advantage of requiring less lead. Considerable advantage has been claimed for the tall type of chamber, but with the exception of the acid plants in connection with the copper smelters it has not been employed in the Southern States.

Water in the form of steam or very fine spray is introduced into the first chamber. This decomposes the nitrosulphuric acid into sulphuric acid and returns the oxides of nitrogen to the system. Water sprays are used in preference to steam.

The gases pass from the first to the second chamber and so on through the system, sulphuric acid being formed until the sulphur dioxide is practically exhausted. The residual gases, which consist largely of the oxides of nitrogen, finally arrive at the Gay Lussac tower, which is similar in construction to the Glover tower, except that it is usually taller and wider (from 40 to 50 feet tall and 8 to 15 feet across). It is partly filled with hard coke, down which trickles strong sulphuric acid (1.5 to 1.7 specific gravity).

The higher oxides of nitrogen are absorbed by acid of this strength, which, after diluting, is returned to the system through the medium of the Glover tower, as already described.

#### EFFICIENCY.

The efficiency of an acid plant is measured, first, by the amount of chamber space required for each pound of sulphur burned in 24

hours and the quantity of acid (50° Baumé or 1.53 specific gravity) made therefrom, and, second, on the amount of niter consumed or lost in the production of this acid.

Numerous patents have been taken out with a view to cutting down the chamber space required. Some of these have proved fairly successful and are used at a number of the acid plants in the Southern States. The chamber space required for the production of acid may be decreased by a more thorough mixing of the gases and by cooling them down so that the acid produced will condense more quickly. In a patented process, much used in the South, the gases are drawn through the first chamber by means of a fan, then through a tower down which flows dilute sulphuric acid, and finally they are reinjected into the front of the first chamber by means of the same fan. This circulatory system is very complete, and there are practically no dead corners in the first chamber. This system requires only 8 to 9 feet of chamber space for every pound of sulphur burned in 24 hours and produces 1 pound of sulphuric acid (50° Baumé) for every 1.5 to 1.7 cubic feet of chamber space.

Other methods for cutting down the chamber space depend on the cooling effect on the gases obtained by passing them through towers arranged inside with corrugated pipes or with plates over which dilute sulphuric acid trickles. The heat necessary to drive off the water from this acid cools the gases and also furnishes the water vapor for further production of chamber acid.

In another patented process, known as the tangent system, as employed at a plant in Baltimore, Md., the gases entering near the top of the chamber are given a spiral motion, which seems to accelerate the reactions and consequently increases the yield of acid. A series of water-cooled pipes are suspended from the top of the chamber to aid in cooling the gases and condensing the acid formed. The uncondensed gases are lead through a pipe or flue in the center of the chamber bottom to the next chamber, where the same process takes place.

This system requires but 6 cubic feet of chamber space for every pound of sulphur burned in 24 hours. But the consumption of niter for such production is about 5.5 per cent of the sulphur burned.

In the chamber process the consumption of niter varies all the way from 3 to 7 per cent of the sulphur burned. In order to avoid loss of the oxides of nitrogen, the Gay Lussac tower must be tall enough and packed in such a way that the acid flowing over the coke will have ample time and present sufficient surface to absorb these gases before they can escape through the stack. There must also be enough oxygen present in the system to prevent the reduction of these gases to lower oxides of nitrogen, which are not absorbed by strong sulphuric acid. During the summer the nitrate consumption is greater than during the winter, but a low average to run on is from 3 to 4 per cent of the sulphur burned.

#### COST OF PRODUCTION.

The average cost of manufacturing sulphuric acid is rather difficult to estimate. The cost varies considerably, depending on the size, type, and location of the acid plant, as well as on the skill with which it is operated.

Since the raw materials are nearly all imported, and can be delivered at the ports considerably cheaper than at inland points, the cost of production is usually less at the coast towns. The lower cost of materials, however, is in a measure counterbalanced by the higher cost of labor at the seaports. When the acid plant is run in connection with the superphosphate factory, which is usually the case, it is difficult to know just how much labor, repairs, and power to charge to each department. The overhead charges also vary between rather wide limits, depending on the size and number of plants operated by the company. In order to bring the cost of production at the various plants to, as near as possible, an equal basis, the overhead or office charges are not included in the following estimates.

At the coast towns the cost of sulphuric acid varies from \$4.50 to \$5 per ton. At inland points, such as Augusta, Atlanta, and Birmingham, it varies from \$6 to \$6.30 per ton.

The following summary shows the itemized cost of production at a plant running at a high degree of efficiency.

*Cost of sulphuric acid per ton (50° Baumé) at plant producing 400 tons per week.*

[Total investment, \$100,000; cost of plant, \$75,000.]

Labor and repairs.....	\$0. 90
Niter, 17.73 pounds (5 per cent of sulphur burned).....	. 39
Pyrites (788 pounds).....	2. 46
Interest on investment of \$100,000 at 6 per cent.....	. 29
Insurance on \$75,000, at 1½ per cent.....	. 05
Taxes on \$100,000, at 1½ per cent.....	. 06
Depreciation on \$75,000, at 10 per cent.....	. 36
Total cost of production.....	4. 51

The above cost is for a plant located at a seaport town, where the price of raw materials is lowest. The plant required but 1.75 cubic feet of chamber space for every pound of acid made in 24 hours.

This production is considered by many acid makers as too high for the amount of chamber space. In other words, a system driven at this rate not only loses sulphur, but is soon eaten away by the hot gases under pressure. The author's observations do not bear out this opinion. Although some of the plants which had been worked under pressure were in need of repair after several years of operation, fully as many were in good condition after having been run for six to eight years. An allowance of 10 per cent should be ample to cover the depreciation at any plant run by a competent superintendent.

The consumption of sulphur per pound of sulphuric acid produced does not appear to be any greater at a plant which is being run under pressure, but the consumption of niter is frequently higher (4 to 5.5 per cent as against 3 and 3.5) than it is at a factory where the rate of production is lower.

Suppose, now, the operations at the above plant were being carried on at one-half the speed, as is the case with a number of acid factories in the South. At best, the depreciation on such a plant would hardly fall below 5 per cent of the investment, and if it requires twice the time to produce the same amount of acid as when it

is run under pressure, the depreciation per ton would not only be the same but all the other costs (excepting niter and pyrites) would be doubled.

Revising, therefore, the cost of production on this basis, we have:

*Cost of sulphuric acid per ton (50° Baumé) at plant producing 200 tons per week.*

[Total investment, \$100,000; cost of plant, \$75,000.]

Labor and repairs.....	\$1. 80
Niter (3 per cent of sulphur burned), 10.64 pounds.....	. 23
Pyrites.....	2. 46
Interest on investment of \$100,000, at 6 per cent.....	. 58
Insurance on \$75,000, at 1½ per cent.....	. 10
Taxes on \$100,000, at 1½ per cent.....	. 12
Depreciation on \$75,000, at 5 per cent.....	. 36
Total cost per ton.....	5. 65

#### WASTE MATERIAL.

In the manufacture of sulphuric acid there are two main sources of waste, namely, the loss of sulphur from the imperfect combustion of the pyrites or the lack of sufficient oxygen in the lead chambers and the loss of the oxides of nitrogen by their escape through the Gay Lussac tower.

In a good works' practice the pyrites should be burned so that the cinders contain less than 3 per cent of sulphur. If, however, the furnace charges are excessive or the draft is insufficient, the furnaces become too hot and "scarring" or the formation of clinkers inclosing unburned pyrites occurs. The formation of these clinkers cuts off the draft still further, and sulphur is driven off and sublimes in the dust flue or Glover tower, and the whole furnace frequently has to be shut off while the clinkers are broken up and removed. Such a condition also causes loss of sulphur dioxide through the system, because the supply of oxygen is not sufficient for the formation of sulphuric acid. With proper regulation of the draft, however, the loss of sulphur can be reduced to a minimum.

The consumption of niter is more serious and in the best regulated systems has never been reduced below 3 per cent of the sulphur burned, the loss sometimes running as high as 12 to 14 per cent. The object of the Gay Lussac tower is to reduce this loss as far as possible by absorbing the oxides of nitrogen and returning them to the system through the medium of the Glover tower, as previously described. If these oxides are reduced, the strong acid trickling down the Gay Lussac tower does not absorb the lower oxides, and they escape into the atmosphere and are lost.

Imperfect combustion of the sulphur or pyrites is attended by a higher consumption of niter, due to the reduction of the higher oxides. On the other hand, too much draft dilutes the gases in the chambers to such an extent that more of the higher oxides are required to effect the necessary reactions. In spite of the great amount of absorbent surface exposed by the acid in the Gay Lussac tower, some of the higher oxides of nitrogen escape into the atmosphere. A more efficient means of absorbing these gases and an economic

method of oxidizing the lower oxides and returning them to the system would mean a considerable reduction in the cost of producing sulphuric acid.

The niter cake or sodium sulphate formed by the action of sulphuric acid on sodium nitrates is sometimes sold, but more frequently thrown away, since the cost of handling it is almost as great as the price obtained for the material. A method for treating this material and rendering it commercially valuable would reduce the cost of acid making in some instances very appreciably. It is to be hoped that it may be available in some such process as the recently described Firmin Thompson method of treating orthoclase for potash.

W. H. WAGGAMAN.

## **APPENDIX E.**

### **MEMORANDUM ON AMMONIUM SULPHATE.**

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#### **INTRODUCTION.**

The necessity for conserving resources and preventing wanton waste, together with the realization that added profits are possible, are leading to a displacement of the old wasteful bee-hive oven by the modern by-product type. The increasing demand for ammonium sulphate has aided this desirable movement, for within the past few years the consumption of this material as a fertilizer has grown to large proportions and the domestic production does not meet the demand. The deficit is partly met by foreign importations, which greatly exceed the present domestic production.

#### **SOURCES OF AMMONIA.**

Ammonia is produced from several industrial sources. First, in the coking of coal, large supplies of coke being required for furnace, foundry, and domestic uses. Second, in the manufacture of illuminating gas, which involves essentially the same process. Third, in the manufacture of bone black for sugar refining. Fourth, from the gases of blast furnaces. Besides these sources, animal ammoniates are produced in large quantities at the abattoirs throughout the country, but these products are used directly as fertilizers without actually extracting the ammonia.

In this country almost the entire supply of ammonia and ammonium sulphate is obtained from the various types of by-product coke ovens and gas works, and to these industries recourse must be had to supply the growing demand for this form of nitrogenous fertilizer.

#### **THEORETICAL AMOUNT OF RECOVERABLE AMMONIA.**

In the destructive distillation (or coking) of bituminous coal three main volatile by-products are obtained, namely, tar, gas, and ammonia. The last of these products is the most valuable, but the quantity produced is considerably less than of the other two products.

Our West Virginia, Pennsylvania, and Alabama coal will yield, generally speaking, about 1 per cent of its weight in ammonium sulphate. Theoretically, therefore, the quantity of ammonium sulphate recoverable is 1 per cent of the bituminous coal consumed. Since much of the coal is burned as fuel, no such production of sulphate can be realized, but it is highly important that the ammonia



should be recovered from all the coal subjected to dry distillation. This would not only be practical, but highly profitable.

#### METHODS OF MANUFACTURING SULPHATE OF AMMONIA.

There are three different processes employed in the extraction of ammonia by the destructive distillation of bituminous coal and the conversion of this ammonia into sulphate. These are the direct method, the indirect method, and the Feld process.

The first two involve the use of sulphuric acid, into which the ammonia gas is passed, but in the Feld process the sulphur in the gaseous products is utilized to convert the ammonia into sulphate. More or less detailed descriptions of these three methods are given by Atwater.<sup>1</sup>

In the indirect method the tar and gases coming from the retorts or coke ovens are passed through a series of condensers, where the tar and some weak ammonia liquor are separated. The gas containing most of the ammonia then passes into the gas washers, which consist of iron cylinders divided into compartments by perforated iron plates. Cold water flowing from the top of the towers or cylinders absorbs the ammonia from the gases bubbling up through the holes in the plates. The solution of ammonia and ammonium salts thus produced is known as weak or crude liquor and contains from 0.5 to 2 per cent of ammonia.

The crude or weak liquor is then pumped to the storage tanks, from which it flows to the stills.

The stills vary somewhat in detail, but the general arrangement is the same. The still proper is in two sections. In the upper part the free ammonia is driven off from the weak liquor by a current of steam, and in the lower part the fixed ammonium salts are decomposed by lime and the ammonia likewise driven off by steam. The ammonia gas is then led below the surface of sulphuric acid contained in a saturator until the ammonium sulphate crystallizes out.

The saturator or neutralizer consists of a lead-lined vessel filled with sulphuric acid and mother liquor from previously crystallized ammonium sulphate. The gases enter through a pipe or bell, also of lead, which dips below the surface of the liquid so that the ammonia is forced to bubble up through the acid, thus insuring perfect absorption. The waste gases are carried off by a flue or utilized to heat the weak ammonia liquor before its introduction into the still.

The partly crystallized ammonium sulphate solution in the saturator is discharged through an ejector into lead-lined troughs, where the salt continues to crystallize as the solution cools. The mother liquor is decanted off and returned to the saturator.

This form of saturator is worked continuously, fresh acid and ammonia vapors being constantly introduced. Sometimes, however, two saturators are alternately employed, the gas being switched to one while the crystallized salt is removed from the other.

The ammonium sulphate is centrifuged or dried in a mechanical drier until it contains less than 1 per cent of moisture. It is then carried to the storage bins by means of a belt conveyer.

<sup>1</sup> "Plants for Sulphate of Ammonia." Advance paper written for sixth annual meeting of Amer. Gas Inst., 1911.

In the direct process as employed at some of the coke-oven plants the ammonia is absorbed directly by sulphuric acid without being first converted into crude ammonia liquor. In this process the temperature of the gas and acid employed is kept down in order to prevent the acid from reacting with the organic constituents of the gas. A certain quantity of weak liquor is produced in the condensers by this process. This must be treated in a still in order to make the recovery efficient.

The Feld process differs considerably from those just outlined. The gases from the distillation of the coal are led up through a washer, down which flows a solution of iron sulphate ( $\text{FeSO}_4$ ) and iron thiosulphate ( $\text{FeS}_2\text{O}_3$ ). This solution reacts with both the ammonia and hydrogen sulphide in the gases, forming ammonium sulphate, ammonium thiosulphate, and iron sulphide. The iron sulphide is separated by both decantation and by means of a filter press, and is then regenerated or converted into iron thiosulphate and free sulphur by passing sulphur dioxide through the sludge. The sulphur is removed by means of a filter press and the solution of thiosulphate returned to the washer and used again.

The solution of ammonium thiosulphate and ammonium sulphate passes into a tank, where it is also treated with sulphur dioxide and then heated by a steam coil, which precipitates sulphur and converts the thiosulphate into sulphate. The precipitated sulphur is separated by a filter press and burned to produce the sulphur dioxide required in this process.

The solution of ammonium sulphate is then boiled under reduced pressure and the salt thus separated by crystallization.

#### PRODUCTION OF AMMONIUM SULPHATE IN UNITED STATES.

Although the number of by-product coke ovens is increasing every year, the quantity of ammonia still lost in the continued coking of coal in the old beehive type far exceeds that actually saved.

The latest official figures of the United States Geological Survey are for 1910. These give the quantity of coal coked for blast furnaces and domestic use as 63,088,327 tons. This tonnage should have yielded approximately 630,000 tons of ammonium sulphate or its equivalent in ammonia, valued at over \$30,000,000, but there were actually marketed only 35,000 tons of ammonium sulphate, 4,654,282 gallons of ammonia liquor, and 10,115 tons of anhydrous ammonia, with a total valuation of \$3,862,196.

The quantity of ammonia and ammonium compounds obtained from the coking of bituminous coals is only about 13 per cent of the quantity which can be saved. According to figures compiled by Atwater<sup>1</sup> this country cokes nearly as much coal as England and Germany combined, yet produces less than one-sixth as much ammonia.

On the following page is given a list of the number of by-product coke ovens in each State. Some of these are still in course of construction, and a few are not running. The ovens vary in coking capacity from 6 to 15 tons of coal every 20 to 24 hours.

<sup>1</sup> Production of Sulphate of Ammonia in 1910, American Coal Products Co., No. 7.

State.	Ovens built and building.	State.	Ovens built and building.
Alabama.....	620	New York.....	556
Illinois.....	480	Ohio.....	174
Indiana.....	610	Pennsylvania.....	1,896
Maryland.....	200	West Virginia.....	120
Massachusetts.....	400	Wisconsin.....	160
Michigan.....	162		
Minnesota.....	50	Total.....	5,278
New Jersey.....	150		

According to figures compiled by the United States Geological Survey the coal coked in 1910 in by-product ovens amounted to 9,529,042 tons, with a theoretical production of 95,290 tons of ammonium sulphate. This theoretical production is not equal to the importations, and the actual production—35,124 tons—is a little more than a third of the importations.

The by-product coke industry in former years centered chiefly about the bituminous coal fields. Now, however, large batteries of coke ovens have been built and are building near the supplies of iron ore in the Great Lakes region. The close proximity of large cities offers a ready market for the gas produced, but the demand for ammonium sulphate is not as great as it is farther east and south.

#### COST OF PRODUCTION.

Since ammonia or ammonium sulphate is only one of the by-products obtained in the gas or coke industry, it is very difficult to arrive at the actual cost of production. An expensive by-product recovery plant is necessary to make the saving of ammonia possible, but the recovery of both tar and gas is also effected by such a plant. The value of all products (particularly the gas) varies considerably, depending on the location of the plant; so it is almost impossible to know what is the average charge which should be made against each of the products. The size of the gas or coke oven plant also affects the cost of production. Some ovens hold a charge of 6 tons of coal, while others have a capacity fully twice as great, without costing proportionately more.

Fulton<sup>1</sup> gives the cost of one of the most modern types of by-product plants at \$5,800 per oven, including the by-product recovery plant. This cost was for a plant of medium size, however, and would no doubt be materially reduced in a larger plant. The following values and costs are based on coal containing 30 per cent of volatile material, coked at a modern plant of about 200 ovens.

The figures by no means apply to all types of ovens and will vary according to the size and location of the plant.

<sup>1</sup> Coke, 2d edition (1909).

*Value of by-products obtained in coking 1 ton of coal (containing 30 per cent volatile matter).*

Material.	Amount obtained.	Market value.	Per cent of total value.
Coke.....	1,400 pounds.....	\$2.42	65.95
Tar.....	6 gallons.....	.14	3.81
Gas (surplus).....	4,000 cubic feet.....	.60	16.35
Ammonia equivalent of ammonium sulphate.....	20 pounds.....	.51	13.89
Total.....		3.67	100.00

*Total cost of manufacturing above products.*

Coal, per ton.....	\$1.180
Labor, per ton of coal.....	.420
Interest on investment, at 6 per cent.....	.102
Depreciation, at 5 per cent.....	.084
Total cost.....	1.796

*Cost of manufacturing ammonium sulphate (20 pounds).*

Cost of ammonia (13.89 per cent of \$1.79).....	\$0.249
Cost of manufacturing ammonium sulphate from ammonia:	
Labor.....	.044
Lime.....	.008
Acid.....	.116
Bags.....	.006
Interest on sulphate plant, at 6 per cent.....	.003
Depreciation on sulphate plant, at 5 per cent.....	.002
Ammonium sulphate:	
Total cost for 20 pounds.....	.428
Cost per ton of 2,000 pounds.....	42.80

**AMMONIUM SULPHATE AS A FERTILIZER.**

Nitrogen in the form of nitrates or ammoniates is the most expensive of the so-called plant foods.

For concentrated high-grade mixtures the animal ammoniates and vegetable nitrogen carriers contain too much natural filler. The nitrogen in these fertilizers is not as quickly "available" as it is in the soluble nitrates and ammonium salts. Nitrate of soda, on the other hand, has the objectionable quality of being deliquescent or absorbing moisture from the atmosphere. In mixed fertilizers the salt causes caking or hardening of the mixture, which makes the material difficult to distribute.

Ammonium sulphate, when properly made, is a dry salt, readily soluble in water. The commercial product is sold on a guarantee of 25 per cent ammonia, much of it running above this figure. As a nitrogen carrier for high-grade mixed goods containing no free lime it has much to recommend it.

W. H. WAGGAMAN.

# APPENDIX F.

## "ALKALI" CRUSTS CONTAINING 0.5 PER CENT OR MORE OF POTASH.

Catalogue No.	Per cent of soluble salts.	Per cent of K in soluble salts.	Per cent of K in soil.	Locality.
4508	13.75	13.67	1.89	Center sec. 15, R. 4 W., 4 miles southwest, care of Buckeye Maricopa County, Ariz.
4518	47.31	9.64	4.56	1/2 mile from bank of river, 1/2 mile south of Buckeye, Maricopa County, Ariz.
4536	4.93	10.16	.50	Salts from side of bluff on north side of Salt River, Phoenix, 15 miles southwest headwaters St. Johns Canal, Buckeye, Maricopa County, Ariz.
4543	6.09	13.14	.80	Crust from bottom of New Arlington Canal, at waste gate, Buckeye, 5 miles southwest.
6517	27.04	2.10	.56	Center north side S. 27, T. 80, R. 24 W., Yuma County, Ariz.
6518	37.81	2.26	.85	Southwest corner 6-40 S., 31 T. S. & R. 23 W., Yuma County, Ariz.
6520	13.91	4.87	.67	Center south side 13-40 S. 36, 98 S., R. 23 W., Yuma County, Ariz.
6521	14.90	3.59	.53	North side 12-40 S. 1, T. 9 S., R. 24 W., Yuma County, Ariz.
6522	19.86	4.63	.91	North side S. 33 T. N. side old international boundary line, Yuma County, Ariz.
6523	7.71	6.50	.50	Center sec. 17, T. 9 S., R. 24 W., Yuma County, Ariz.
6525	20.01	4.24	.85	6-40 D. 9, T. 10 S., R. 24 W., Yuma County, Ariz.
6526	47.41	1.77	.84	14-40 sec. 6, T. 10 S., R. 24 W., Yuma County, Ariz.
544 (1)	12.96	1.86	.61	Fine sandy loam, Yuma County, Ariz.
4661	11.80	7.22	.85	100 yards east of dunes mentioned in Oxnard. Oxnard 3 miles west, Ventura County, Cal.
4662	19.93	5.48	1.09	Edge of lake, 2 miles southwest of house on Patterson ranch, Oxnard, Ventura County, Cal.
4664	22.08	6.02	1.32	From roadside by experiment farm, 1 mile northwest house on Patterson ranch, Oxnard, Ventura County, Cal.
4665	15.06	8.26	1.24	From roadside 1/2 mile east of house on Patterson ranch, Oxnard, Ventura County, Cal.
4794	57.64	1.11	.63	From bank of slough near sand dunes, Patterson ranch, Oxnard, Ventura County, Cal.
4890	54.24	1.26	.68	Center west side sec. 11, T. 17 S., R. 21 E., 2 miles west and 8 south of Selma, Cal.
6182	63.85	.82	.52	Lot 56, La Colonia rancho, Ventura County, Cal.
6183	41.71	1.54	.62	1/2 mile west of Hueneme from bank of sloughs, inside sand dunes, Ventura County, Cal.
6188	38.52	1.42	.50	1/2 mile west of junction of Leguma and Wood Roads, Ventura County, Cal.
712a	37.55	10.64	4.00	4-40, S. 13, T. 41 N., R. 35 E., San Luis Valley, Colo.
1107a	18.60	2.99	.54	North Platte, Nebr.
1166a	9.87	11.55	1.14	Bridewood Ranch, North Platte, Nebr.
439a	82.96	3.77	3.12	Texas.
6673	14.49	4.47	.65	West side 15-46, S. 2, T. 6 N., R. 35 E., Walla Walla, Wash.
6676	17.50	3.07	.54	Northwest corner 3-40, S. 12, T. 6 N., R. 35 E., Walla Walla, Wash.
6677	14.78	4.33	.64	East side 10-40, S. 27, T. 7 N., R. 35 E., Walla Walla, Wash.
6682	49.64	1.25	.62	Sec. 28, T. 7 N., R. 34 E., north side, Walla Walla, Wash.

## APPENDIX G.

### LIST OF PATENTS FOR THE EXTRACTION OF POTASH SALTS.

No.	Name.	Patent.
8,308	E. L. Seymour.....	Proposed treatment of feldspathic rocks with sulphur dioxide, air, and steam.
16,111	Chas. Bickell.....	Heats 1 part of feldspar, $\frac{1}{2}$ part of calcium phosphate, and 3 or 4 parts of lime. Ground mass is applied directly as fertilizer.
1,607	Jacob Osborn.....	Extraction of potash from wood ashes.
216,483	J. and R. H. Woodrum.....	Extraction of potash salts from ashes.
446,287	Bernard Peitzsch.....	Separation of potash salts from kainit and similar minerals.
513,001	H. S. Blackmoore.....	Heats feldspar, calcium chloride, and lime to 1,100° C. in a sealed furnace.
641,406	J. G. Rhodin.....	Feldspar heated with lime or calcium carbonate and salt. The powdered mass is treated with acid.
772,206	H. S. Blackmoore.....	A dried, powdered potash silicate is mixed with water and subjected to the action of carbon dioxide at 500 pounds pressure. Alkaline bicarbonates are obtained.
772,612 772,657	W. T. Gibbs.....	{ Treats silicates with hydrofluosilicic acid. Potassium fluosilicate formed. This is mixed with sulphuric acid to give potassium sulphate and hydrofluosilicic acid.
789,074	A. J. Swayze.....	Heats silicates with calcium sulphate and a reducing agent such as coal. The potash salts are volatilized.
847,856	W. E. Wadman.....	Heats lepidolite with potassium sulphate. On lixiviating, lithium sulphate and part of the potassium sulphate go into solution. The residue is decomposed by sulphuric acid. The potash in the mineral and also that added is thus recovered.
851,922	A. S. Cushman.....	Electrolytic endosmosis, in the presence of water, or dilute hydrofluoric acid.
862,676	A. J. Swayze.....	Heats silicates with potassium hydroxide solution. The latter extracts the silica, alumina, and potash as potassium silicate and aluminate.
869,011	R. H. McKee.....	Heats potash-bearing minerals containing mica with lime and salt.
896,168	Sylvester Sparlin.....	Chars sagebrush and lixiviates with water.
910,662	W. T. Gibbs.....	Heats silicates with alkaline earth hydrates under pressure.
912,266	A. C. Spencer and E. C. Eckel	Greensand or similar rock is heated with lime or dolomite. The potash volatilizes. The residue is used as a cement.
957,295	Augusto Alberti.....	Recovery from wine lees, crude cream of tartar, etc. The treatment is with hydrochloric or sulphuric acid giving free tartaric acid and the potassium salt. Lime is added and calcium tartrate precipitated. Hypochlorous acid is used to oxidize organic matter in the filtrate.
959,841	F. R. Carpenter.....	Heats potash-bearing rocks to a high temperature and then suddenly chills them. They are thus made amorphous, and the claim is made that after grinding the potash is soluble in acids.
987,436	A. S. Cushman.....	Heats finely ground feldspar and calcium chloride with or without lime. The potassium salts are obtained by volatilization or leaching, or by both.
996,106	Firman Thompson.....	Feldspar, acid sodium sulphate, and sodium chloride are heated together. The products are potassium chloride, sodium sulphate, and hydrogen chloride.
997,671	Edward Hart.....	Fuses orthoclase with barium sulphate and coal. The fused mass is decomposed by a mineral acid, yielding a residue which may be used as a pigment.

APPENDIX H.

MEMORANDUM IN RE SALINE CLAIMS, POTASH DEPOSITS, ETC.

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UNITED STATES DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS,  
September 25, 1911.

DEAR SIR: We would appreciate it very much if you would have prepared for us a brief summary of the United States laws controlling the filing of saline claims. This summary should describe the size and number of permitted filings, the means of classification of the lands, the amount of required assessment work, the time within which it must be done, and any similar matters which control the obtaining of patents.

This information is required in connection with our investigation of possible potash deposits in the United States.

Yours, very truly,

A. G. RICE, *Chief Clerk.*

GEO. P. McCABE,  
*Solicitor Department of Agriculture, Washington, D. C.*

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[Memorandum for the chief clerk Bureau of Soils.]

OFFICE OF THE SOLICITOR,  
UNITED STATES DEPARTMENT OF AGRICULTURE,  
September 28, 1911.

I am in receipt of your letter of September 25, 1911, requesting a brief summary of the United States laws relating to saline claims. You state that such information is required in connection with your investigations of possible potash deposits of the United States.

The statute authorizing the filing of what are commonly known as saline claims, viz, the act of January 31, 1901 (30 Stats., 745), reads as follows:

That all unoccupied public lands of the United States containing salt springs or deposits of salt in any form, and chiefly valuable therefor, are hereby declared to be subject to location and purchase under the provisions of the law relating to placer-mining claims: *Provided*, That the same person shall not locate or enter more than one claim hereunder.

You will note that the location and purchase of saline lands of the character described are controlled by the provisions of the law relating to placer-mining claims, except that in the case of the former the right of location and patent is restricted to one claim of 20 acres for each person. The Secretary of the Interior holds (35 L. D., p. 1) that the act of January 31, 1901, *supra*, applies only to common

salt (sodium chloride), and would thus not govern the disposal of public lands valuable for their deposits of potash. I am of the opinion that public lands valuable for their potash deposits may be located and purchased under the placer-mining laws, the same as any other lands valuable for their placer deposits, without being subject to the restrictions as to the number of claims that may be taken up by each person which is imposed in the case of so-called saline claims, under the act of January 31, 1901.

For your information I append a copy of the General Land Office circular of March 29, 1909, embodying the United States mining laws, and regulations thereunder. Your attention is called to the specific portions of the circular relating to placer claims. I also have prepared below, for your convenience, a brief outline of the principal steps to be taken in consecutive order, in the acquisition of claims under the placer-mining laws.

#### PLACER CLAIMS.

##### PRELIMINARY.

1. *Lands subject.*—Public mineral lands of the United States in the following States, Territories, and District of Alaska, containing any form of valuable mineral deposit, except veins of quartz or other rock in place: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North and South Dakota, Oregon, Utah, Washington, and Wyoming.

2. *Size and form.*—May be taken in units of 10-acre tracts, being subdivisions of 40-acre legal subdivisions. Single claim may not exceed 20 acres for any one person or corporation, or if taken by an association may not exceed 20 acres to each individual in the association, or 160 acres to the entire association.

3. *By whom.*—May be located and entered by citizens of the United States (including corporations chartered therein) or by persons who have declared their intention to become such.

##### MODE OF ACQUISITION.

1. *Discovery.*—There must be such a discovery of mineral on the land as will show that it has a special value for the deposit claimed.

2. *Location.*—(a) Posting location notice in a conspicuous place on the claim.

(b) Staking claim, which must be distinctly marked on the ground so that its boundaries can be readily traced.

(c) Recording in the place provided by law of the location certificate, which must contain the name or names of the locators, date of location, and such description of the claim or claims located by reference to some natural object or permanent monument as will identify the claim.

NOTE.—Provisions of State law should be strictly followed in locating the claim.

3. *Annual labor or assessment.*—Not less than \$100 worth of labor shall be performed or improvements made during each year, but the periods within which such work is required to be done does not commence until the 1st day of January succeeding the date of location of the claim.



4. *Statutory expenditure.*—At least \$500 worth of labor must have been expended or improvements made upon the claim by the claimant or his grantors before entry or patent will be allowed.

5. Request for survey of claim, addressed to United States surveyor general for proper district.

6. Survey of claim under authority of surveyor general.

7. Posting of notice of intention to apply for patent, together with plat of official survey, in a conspicuous place on the claim.

8. *Application for patent* must be filed in local land office, with necessary accompanying papers, including proof by affidavit of two witnesses of posting of aforesaid notice; copy of approved plat and field notes of survey; abstract of title; certified copy of original location notice; affidavit of citizenship; agreement of publisher; notice for publication, etc.

9. *Publication of notice of intention to apply for patent and posting of copy of same in local land office.*—Notice of intention to apply for patent must be published in newspaper published nearest the claim and designated by register and receiver for 61 days if a daily paper or nine consecutive weeks if a weekly.

10. *Application to purchase.*—Filed in local land office, with necessary accompanying papers, including proof of publication of notice, proof of \$500 expenditure, etc.

11. Payment of purchase price, \$2.50 for each acre or fraction thereof.

12. Entry.

13. Patent.

I have not considered it necessary here to give a complete enumeration of the papers required to accompany the application for patent and application for purchase, but you will find the same covered by the appended circular of the General Land Office. If there are any other points relating to placer mining claims on which you desire to be informed, I shall be glad to advise you upon your request.

Respectfully,

H. J. FEGAN,  
*Acting Solicitor.*

APPENDIX I.

MEMORANDUM IN RE JURISDICTION OVER KELP GROVES.

UNITED STATES DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS,  
October 5, 1911.

DEAR SIR: In accordance with the investigation which we are making of the fertilizer resources of the country, with special reference to the possibility of utilizing kelp beds as a source of potash, the question has arisen as to the jurisdiction over these beds and what parties are entitled to cut them. Some of the beds lie outside the nautical league limit, but many of them, including the more important ones, are within this limit. These beds all grow either in strong tideways or on the exposed coast, where there is a heavy swell.

The cutting of these beds in a small way has already commenced on the Pacific coast, and the question as to whether the jurisdiction over these kelp beds lies with the National Government or with the State authorities is already one of practical importance, and it is of considerable moment that we be advised in this matter before planning or carrying on further investigations in this direction.

Yours, very truly,

R. F. CUMMINGS,  
*Acting Chief Clerk.*

SOLICITOR, DEPARTMENT OF AGRICULTURE,  
Washington, D. C.

(Memorandum.)

UNITED STATES DEPARTMENT OF AGRICULTURE,  
OFFICE OF THE SOLICITOR,  
October 12, 1911.

SIR: I have Mr. Cummings's letter of the 5th instant asking to be advised as to whether the jurisdiction of kelp beds along the coast, both within and outside the 3-mile limit, is within the State or the Federal Government.

Jurisdiction over the shores of the sea below the line of high tide and for a distance of 1 marine league or 3 geographical miles out to sea from the line of low water is wholly within the respective States, subject to the paramount right of the Federal Government to regulate commerce and navigation, while the sea beyond the 3-mile limit is open to all the nations. Bays whose headlands are not more than 6 miles apart, measuring from low water, are subject to the same extent to the jurisdiction of the State within which they lie. The right to regulate the taking of kelp within the limits above described is therefore within the several States, while neither the State nor the Federal Government has any control over the water beyond that limit.

Very respectfully,

GEO. M. McCABE, *Solicitor.*

CHIEF OF BUREAU OF SOILS,  
*Department of Agriculture.*

APPENDIX K. *revised*

THE KELPS OF THE UNITED STATES AND ALASKA.

The kelps or oarweeds, in popular language, are the members of the botanical family Laminariaceae and belong to the algae or seaweeds of the Phaeophyceae or brown group. In general they are large, brown or olive-green seaweeds, of complex structure, more or less tough or leathery, having a more or less stout stalk or stipe, simple or branched, surmounted by a fairly long flattened blade (or blades), with the region whence growth in length proceeds situated between the stipe and blade, and bearing the organs of fructification in broad, dark, flattened and thickened cloudlike patches (usually on the blade).

The first distinguishing mark of a kelp is that it is brown. This means that the color when fresh is typically of a lighter or darker brown (as distinguished from blue, green, or red), or it may be either so brown as to be almost black, or so light as to be simply olive-green. This color is due here, as in all other brown algae or seaweeds, to the presence of a brown pigment, called Phycophaein, in addition to the green pigment or chlorophyll. Phycophaein is slightly soluble in water, but is more completely soluble in dilute alcohol, while chlorophyll is only soluble in strong alcohol.

The kelps are all complex, i. e., they are solid structures made up of several distinct tissues or collections of cells. The central or medullary tissues are made up, as a rule, of elongated—often tubular—cells, and have for their function the conduction of substances manufactured and distributed from the outer tissues. They are destitute of assimilating cell organs, the chromatophores or chlorophyll granules. The outermost layers are composed of small cells, nearly isodiametric, which contain the chromatophores and are consequently the assimilating tissues. The intermediate tissue or tissues—the mechanical—are more or less complex, according to the size of the plant or the part concerned, consisting of cells from those nearly isodiametric to those decidedly elongated vertically. They (or only the outermost ones in the complex structures) also take more or less part in assimilation.

The typical kelps (i. e., all except a few aberrant forms) have at least three sets of organs, viz, holdfast, stipe (or stalk), and lamina (or blade). In the great majority these three organs are well developed, and in some of the higher forms the stipe and lamina may become very complex.

The holdfast may be either discoid and solid or branching. Few forms have the discoid holdfast. The majority of species have more or less dichotomous hapteres (or branches), given off irregularly or in more or less distinct whorls from the very base of the

stipe. In either case, the disk or the tips of the hapteres apply themselves to rocks, stones, or other large algae, to which they adhere tightly, through mucilaginous modification of the walls of the cells of the contact surfaces. They are then to be wrenched free only with difficulty. The holdfast in one case (*Saccorhiza bulbosa*) is a large bulblike organ with many whorls of hapteres, and reaches a diameter of several inches to a foot. The holdfast of the long kelp of the Pacific and Antarctic Oceans is a branched affair, often more than a foot in every diameter. Some kelps (e. g., *Laminaria rodriquezii*, *L. sinclairii*, *Dictyonereon californicum*, *Macrocystis*, etc.) have prostrate rhizomes of greater or less length, which give off hapteres and form new fronds.

The stalk or stipe may be longer or shorter, vanishing at times in the adult stage, cylindrical or flattened, and simple or branched. Very few kelps lack the stipe in the adult stage, but all have it distinct in the younger stages. In some of our Pacific coast forms the stipe may reach a length of one to two (?) hundred feet. In a few kelps also (*Saccorhiza bulbosa* and species of *Undaria*) the stipe becomes very much flattened, winged, and furbelowed. The stipe increases in length at its summit.

At the summit of the stipe (or of its branches) is situated the blade (or blades). These are longer or shorter, broader or narrower, entire or split, plane, ruffled, ribbed, plicate, or perforated. In fact, there is the greatest variety of outline and marking to be found. The stipe expands above into the blade, which wears away at its tip and is renewed at its base. Thus the meristem for increase in length of both stipe and blade is situated at the transition place where one passes into the other. Whatever the markings or other modifications of the blade may be, the base is usually plane. However, in two species (*Agarum turneri* and *Thalassiophyllum clathrus*) the blade unrolls at the base from two scrolls, and in another genus (*Arthrothamnus*) the base of the blade has two prominent auricles. The members of one tribe (*Ecklonieae*) have the base of blade deeply lobed. In some cases (*Hedophyllum subsessile*, *H. spiralis*, *Arthrothamnus*, and *Eisenia*) the bases of the blade thicken, the central portion of the blade wears away, the thickened bases increase in length, separating the margins which appear then as separate blades, while the thickened bases of the blade appear as if branches of the stipe.

Outside of the various ruffles, ribs, folds, perforations, etc., which give variety to the appearance and structure of the blade, the blade, as well as stipe, may be increased in complexity in two ways, viz, by splitting and by outgrowths. Both of these have their beginning at the transition place and affect both stipe and blade equally or only the one or the other. Further details of these will be given under the proper subfamilies (Lessonioideae, Lessoniopsoidae, and Alarioideae).

The fructification of the various members of the kelp family, or Laminariaceae is comparatively of very simple structure. To the naked eye it is seen to form more or less extended patches, or sori, on the surface. The sori are usually more or less irregular in outline, and are, as a rule, of a color darker than the adjacent portions of the plant and slightly elevated. In the majority of species, the sori are situated upon one or both surfaces of the blade, extending

at times over its whole surface, at times forming definite spots, or in a few cases (*Postelsia* and some forms (?) of *Macrocystis*) being restricted to lining the longitudinal furrows of the blade. In some species the sori are restricted to specialized leaflets (e. g., in the *Alarioideae*) or sporophylls. In two cases (*Saccorhiza bulbosa* and *Undaria* (?)) the sori occur on the "furbelows" of the stipe.

In all cases the sorus is made up of two sets of elongated elements—unilocular zoosporangia and unicellular paraphyses—closely packed together in a palisadelike fashion, with their long axes perpendicular to the surface on which they are borne. They are covered by a thin but dense transparent membrane, the cuticula, which separates at maturity and falls off. The zoosporangia are elongated, more or less clavate cells, whose contents are deep brown in color and divide to form a considerable number of zoospores. The paraphyses are elongated, generally slender cells, whose contents are deep brown and whose tips, in the great majority of species of the family, are topped by a thick, hyaline, cuticular appendage. A few genera have paraphyses which lack this.

The *Laminariaceae*, or kelp family, then, is a family of the *Phaeophyceae*, or brown algae, whose plant body is differentiated into holdfast, stipe, and blade, of solid structure, having the primary region of growth in length intercalated between stipe and blade, and with unilocular zoosporangia and unicellular paraphyses compacted into extended patches or sori.

Concerning the earliest stages in the development of the *Laminariaceae*, there is very insufficient information of any certain nature. It has been held probable that the unilocular sporangia among the *Phaeophyceae*, or brown algae, give rise to zoospores, i. e., the small bodies emerging from them, bearing two laterally attached flagella, germinate without fusing. It is fairly certain that they do thus germinate. Many years ago Areschoug (1875, 14, 15) noticed that while some zoospores of *Chorda tomentosa* germinated singly, others, situated in pairs, put out tubes toward one another which touched (1875, p. 15, pl. 1, f. 10 and 11). Areschoug did not think that this represented a sexual act such as he had observed in the case of *Dictyosiphon hippuroides* (loc. cit., p. 27, pl. 3, f. 7-12), which, in turn, possesses only the unilocular type of reproductive organ. The observations of Thuret (1851, pls. 29 and 30) indicate that for *Chorda filum*, *Laminaria saccharina*, and "*Haligenia bulbosa*," the "zoospores" germinate without fusing. Lately, however, Drew (1910, p. 184, etc.) claims to have observed conjugation in *Laminaria digitata* and *L. saccharina*. As a consequence, he calls the unilocular bodies "gametangia," and, because of certain peculiarities in germination, the cells immediately arising from them "sporophytes." From these cells arise singly the plants which develop into the typical *Laminaria* plants, which are called gametophytes. The whole matter seems to need confirmation, and there seems to be no warrant, morphological or cytological, for the application of the terms sporophyte and gametophyte. It seems best still to call the "unilocular sporangia" by that name awaiting further investigation. The later stages, as figured by Drew (loc. cit.), are hardly so convincing as those so beautifully figured by Thuret (loc. cit.) for "*Haligenia bulbosa*," and equally so by Yendo for *Costaria* (1911, Pl. LIII, f. 1-10), who also described them. Although the

chain is not as yet complete, it seems that the Laminariaceae first form a longer or shorter filament of cells, which soon begins to divide so as to form a simple membrane, and this passes over gradually into a solid flattened structure above with the cylindrical stipe forming below. These stages, in more or less completeness, have now been described by several writers, and there is some agreement to call these earlier stages up to the formation of the simple laminarioid frond the embryonal stages.

Just where we are to draw the line between the embryonal stages and the later postembryonal stages may be difficult, especially in the simpler genera, but in complex genera there is less difficulty. The various midribs, etc., may appear early and be reckoned as belonging to the embryonal stages, and other modifications may also appear, but after the frond is fairly well formed, with blade, stipe, and hold-fast differentiated, there are secondary changes, more ribs, bullose swellings, thickenings of the blade and stipe, etc., which are distinctly postembryonal, and in the species whose fronds become complex by splitting or outgrowths these changes may well be placed among the postembryonal stages.

Beginning thus, with a simple Laminarioid plant which may show some differentiation, all the members of Laminariaceae, recapitulating their phylogeny (cf. Griggs, 1909), proceed to differentiate into their various adult conditions, the process varying in detail and complexity according to the species. There are, however, three, or perhaps more properly four, main lines of differentiation, viz, those of the subfamilies, and under each, few to several minor lines, those of the tribes, with generic and specific modifications under these. It may be well, then, to pass to a review of the various subfamilies, in order to make clear the adult morphology as well as the post-embryonal stages.

In looking over the Laminariaceae we find that, in spite of its compactness, there are at least three, probably four, fundamental types of adult structure:

- (1) The simple or Laminarioid type. In this type the stipe is not branched, nor does the blade become compound by any process of splitting or outgrowth. Certain complexities do arise in a few forms, but no such definite methods exist as in the other two types for increase in complexity.

- (2) Both blade and stipe become compound by a splitting process, which takes place in the primary meristem or growing region at the transition place between stipe and blade. In this way a few to a many branched stipe arises, the ultimate branches each surmounted by a leaf.

- (3) From the transition place there grow out smaller blades, which may be mostly on the side of the blade or mostly on the side of the stipe, or on both.

- (4) When one of these sources of complexity exists the other is not present, but there is one kelp (*Lessoniopsis*) in which it has recently been discovered that both exist side by side.

In the classification to be adopted in this account, members of the family Laminariaceae belonging to the first type will be placed in the subfamily Laminarioideae; those of the second type in the subfamily Lessonioidae; those of the third type in the subfamily Alarioideae; while the plant of the fourth type will be placed in a

subfamily if its own, to be called *Lessoniopsoideae*. Each of these subfamilies, with the exception of the last, will be divided into two or more tribes, to further segregate the genera. All the members of these subfamilies and tribes have their peculiar postembryonal stages, which will be considered later in the proper places in the systematic account.

#### CONDITIONS OF LIFE.

*Relation of bathymetric zones.*—The kelps grow from just below high-water mark down into depths of perhaps 200 meters or more, the majority of species growing either just above or just below extreme low-water mark. The temperature and conditions of the moisture in the atmosphere undoubtedly have their effect on the various species, especially those inhabiting the littoral zone (taken as the region between the highest high and lowest low water marks).

Only a very few kelps grow high up in the littoral zone, unless in tide pools—e. g., *Laminaria sinclairii* on the coast of California, *Hedophyllum sessile* from the northern coast of California north to Puget Sound, and in Alaska *Alaria lanceolata* and *Hedophyllum subsessile*. *Postelsia palmaeformis* and *Lessoniopsis litoralis* grow even higher up where the waves dash high. The majority of kelps grow just at the lower limits of the littoral zone or in the first few meters of depth below it, in the sublittoral zone. Some kelps live in 30 to 40 meters of water, attached to stones, and send their stipes and blades toward or even up to the surface, bouyed up by bladders of various sizes and number. Such are, e. g., *Macrocystis*, *Nereocystis*, *Pelagophycus*, *Egregia*, and *Alaria fistulosa*. In favorable localities kelps are reported as growing at depths of from 100 meters to 150 meters.

D. C. Eaton mentions (1873, p. 343) that, at Easport, Me., the dredge brought up a specimen of *Haligenia dermatodea*, with the stipe freshly cut, from a depth of 25 fathoms (50 meters) and the lobster fishers of the eastern end of Long Island Sound claim that they find lobsters among kelps in "The Race" at a depth of 100 fathoms (200 meters) and over. The usual depth, however, does not probably much exceed 30 to 40 meters, except possibly where the water is unusually clear. *Laminaria rodriguezii*, e. g., was found by Rodriques at a depth of 105 to 150 meters (cf. Bornet, 1888, p. 364), and it seems to be confined to these depths. Kjellman says (1883, p. 10) that the elittoral zone of the Arctic Sea is, for the most part, destitute of algae, and it seems that he found Laminariaceae at no greater depth than 10 fathoms (20 meters). Dickie (1853) found *Agarum costata* at 10 to 100 fathoms (20 to 200 meters) and *Laminaria* ("*L. saccharina*") at 50 to 100 fathoms (100 to 200 meters) in Baffin Bay. On the Alaskan coast I have seen *Nereocystis* growing in 12 fathoms of water (cf. Setchell, 1908, p. 126).

*Relation of substratum.*—The Laminariaceae, like other fixed algae, depend upon a firm foothold, and are found affixed to rocks, stones, shells, wood, iron, and to other large algae. In the littoral and upper sublittoral zones, where they are exposed to the pounding and wrenching effects of the waves, they are attached to rocks or large stones firmly fixed, or to the piles and other timbers of wharves. A favorite habitat of some kelps are buoys, either the wooden or the

painted iron buoys. In the deeper water, even large kelps like the *Nereocystis*, *Macrocystis*, and *Pelagophycus* are attached to comparatively small stones or shells firmly fixed in the mud. In the littoral zone, some kelps, notably *Laminaria stenophylla* find a firm attachment on mussels (*Mytilus edulis*, etc.) in exposed situations. The Laminariaceae are less often epiphytic, but *Nereocystis*, e. g., is often found growing on *Pterygophora* and the Laminariae of the New England coast, are sometimes found, especially in juvenile stages, growing on slender but tough algae like *Desmarestia aculeata*. While some of the kelps, like *Macrocystis*, *Pelagophycus*, *Nereocystis*, *Alaria fistulosa*, etc., float for long distances, they make no growth except when attached and ultimately perish when torn from their substrata.

The nature of the shore exposed by low tides and the nature of the bottom is one of the important factors in determining the presence or absence of algae in general, and of the Laminariaceae in particular. The Laminariaceae need a strong or rocky bottom where the rocks are solid and not disintegrating, or the stones fixed firmly in the clay. On sandy or muddy shores or bottom, as well as on those composed of shales or other disintegrating rocks, indeed, even on gravelly and shelly bottoms where other algae may abound, no growth of the Laminariaceae is to be expected. On the other hand, the rocky and stony shores and bottoms of the temperate and frigid waters, where other physical conditions are at all favorable, a luxuriant growth of Laminariaceae may be expected. This is especially true of the colder waters.

*Relation of salinity of the water.*—Exact figures are wanting to enable a discussion of the influence of the varying salinity of the water to be carried on satisfactorily. Recourse can be made only to general experience, and statements can be couched only in general terms. In general, it may be said that the Laminariaceae do not inhabit brackish water. A few, indeed, do ascend tidal rivers to a slight extent, but not nearly so far as do the Fucaceae or the Ulvaceae. The Laminariaceae are found in greatest abundance and luxuriance where the water is purest, i. e., in the ocean and larger bodies of water and away from the localities where large volumes of fresh waters are discharged. In looking for large bodies of kelps, then, it will be necessary to examine those stretches of coast where the salinity of the water is not likely to be lowered by the discharge of fresh water from large rivers.

*Relation of temperature.*—The members of the Laminariaceae are to be found only in the temperate and colder waters. They are absent from the strictly tropical waters, i. e., waters having a temperature of 25° C. and over. In waters somewhat below 25° C., down to 0° C. and even to -2° C., kelps are found; and while a few species range through all the degrees, most kelps are more or less narrowly restricted in their temperature limits. Some years ago (cf. Setchell, 1893) I showed this to be the case, and the results I presented have been little changed by the progress of our knowledge since that time. In that paper I attempted to show the different regions or centers of the distribution of the Laminariaceae and brought out the fact, although not emphatically, that they vary from one another either in geographical isolation or in temperature. I also showed that the



different tribes of the Laminariaceae affect different temperatures to a certain extent. The differences in temperature may be seen from that discussion to amount to 5° C. in the important cases. To illustrate, there are on the eastern coast of North America three separate regions so far as Laminariaceae (and other algae as well) are concerned, viz, the Baffin Bay region, which extends somewhat southward along the Labrador coast; the southern coasts of Labrador; the coasts of New England, down as far as Cape Cod; and, finally, the southern coasts of New England, and even those of New Jersey. The maximum summer temperature of the two uppermost regions varies from 0° C. to 20° C., and that of the lowermost from 20° C. to 25° C. Each has its own assemblage of kelps, and there are some indications of a subdivision in the case of the middle division. Even more distinct are the conditions of temperature limiting the distribution of algae, including the Laminariaceae, on the Pacific coasts of North America. From Bering Strait down to Magdalena Bay in lower California there is to be found an abundant kelp-flora. This flora may be divided into four distinct assemblages: (1) That of the Bering Sea region; (2) that of the Alaskan coast to, and including, Puget Sound, i. e., down as far as Cape Flattery; (3) that extending from Cape Flattery on the coast of Washington to Point Conception on the coast of California; and (4) that of the coasts south of Point Conception to, and including, Magdalena Bay. Below Magdalena Bay there are no Laminariaceae on the coast of North America (cf. Setchell and Gardner, 1903, pp. 167-171). It has seemed best to speak of these regions as the upper boreal, the lower boreal, the north temperate, and the north subtropical regions (Setchell and Gardner, loc. cit.). These regions differ from one another by 5° C. of temperature. The surface waters of the upper boreal range from 0° to 10° C., the lower boreal from 10° to 15° C., the north temperate from 15° to 20° C., and the north subtropical from 20° to 25° C. The upper boreal region (Bering and Ochotsk Seas) has such Laminariaceae as *Laminaria longipes*, *Thalassiophyllum clathrus*, *Lessonia*, *Laminariaeoides*, *Arthrothamnus bifidus*, *Hedophyllum sub sessile*, *H. spirale*, and probably some others. It has not been at all thoroughly explored, but lacks most of the species of the lower boreal, including such conspicuous plants as *Macrocystis* and *Nereocystis*, which are abundant in the lower boreal region. It has *Agarum costata*, a species of the eastern coast. The lower boreal has a most abundant kelp-flora, with some Arctic and North Atlantic species, such as *Laminaria saccharina* in several forms and *Alaria dolichorhachis*. It has peculiar species, such as *Cymathaere triplcata*, *Pleurophyucus gardneri*, *Agarum fimbriatum*, *Laminaria bullata*, and *Hedophyllum sessile*. In the Puget Sound region, as used in the larger sense, there is a mingling of colder and warmer waters and a consequent mingling of the floras of the lower boreal and the north temperate. It is a very rich algal flora. Here are found most of the characteristic lower boreal forms and such north temperate kelps as *Laminaria ephemera*, *Postelsia*, *Dictyonereis*, *Egrecia menziesii*, *Pterygophora*, and *Lessoniopsis*. In the north temperate there are the species just mentioned and *Macrocystis*, *Nereocystis*, *Laminaria sinclairii*, *L. farlowii*, and *L. andersonii*. There are fewer species of *Alaria*, and the Atlantic and Arctic species, *Laminaria saccharina*

and *Alaria dolichorhachis*, are absent. There is a belt of cold water on the northern Californian coast, and here *Hedophyllum sessile*, characteristic of the lower boreal, reappears at a congenial temperature. The north subtropical region lacks in ordinary waters all species of the north temperate region, so far as the Laminariaceae are concerned, except *Laminaria farlowii* and *Macrocystis*. It has, however, at particular points, whose depths are washed by a submarine cold current, *Agarum fimbriatum* of the lower boreal and *Pterygophora californica* of the Puget Sound and north temperate regions. As characteristic species for this lowest region are *Pelagophycus porra*, *Eisenia arborea*, and *Egregia laevigata*.

*Macrocystis pyrifera* has the longest range on our western coasts, and through the most degrees of surface temperature, of any kelp. It extends from Lower California to beyond Sitka, in Alaska, and from 25° C. down to 10° C., a range of 15°. Why it does not pass into water of 5° C. is a mystery, since at Cape Horn and the Falkland Islands what appears to be the same species abounds in water entirely below the isotherm of 10° C. Some of the Laminariaceae range through 10° C., but most of them seem to be restricted to waters whose variation is within 5° C., or nearly so. This seems to be general among algae.

From what has been detailed above, it seems that in the shores of the oceans, apart from localities affected by particular conditions otherwise, the temperature of the water is the controlling factor in deciding and limiting the distribution of the Laminariaceae.

*Relations of light.*—The Laminariaceae, being chlorophyll-possessing plants, need light. This is probably the most important factor in determining their distribution in depth. In perfectly clear water the kelps can grow deeper than in water which is turbid, because of the greater penetration of the light. There is a noticeable decrease in the intensity of the color in kelps which grow in shallow water. They are a light brown and often decidedly yellowish.

*Relations to air.*—It may be said that kelps usually grow in water which is in motion. This is particularly true for the kelps of the littoral zone. So far as I know, the kelps which grow on the rocky shores and tide pools in the littoral zone are all to be found on such stretches as are exposed to the full force of the waves and are constantly bathed in water which is churned up with air. Consequently they come into contact with the dissolved gases from the atmosphere as well, as the water in which the air exists is in a state of active effervescence. Plants occupying such a habitat are known as surf plants, or cumaphytes. (Cf. MacMillan, 1899, p. 279.) There is every gradation among these cumaphytes from those preferring the most violent surf to those sheltering themselves from all but its gentlest influence. *Postelsia* and *Lessoniopsis*, for example, grow on the most exposed point and at or only just below high-water mark, where they receive the full force and "boil" of the strongest waves. *Laminaria sinclairii* and some *Alariae* grow at about mid-tide area, where the waves, while strong, are much less so than in the first instance. *Hedophyllum sessile*, which also grows high up in the littoral zone, nevertheless inhabits more sheltered nooks. The majority of the "shore" kelps live in the lower portions of the littoral or the upper regions of the sublittoral, where they receive much ben-

efit from the aerated waters without being subject to the full severity of the pounding, or even the wrenching forces of the waves. The kelps of the upper and also of the lower sublittoral zone grow where there are currents of water, in tideways, or exposed to shore currents, and even the inhabitants of the deeper waters grow where they may benefit from constant movements of the water and not far from shore. *Macrocystis*, *Nereocystis*, and *Pelagophycus*, even, will not grow in quiet waters, and if their accustomed haunts are shut off from full influence of the "swells," they perish and are not renewed. Such was the case at San Pedro, in southern California, when a break-water was constructed to protect the harbor. The *Macrocystis* and *Pelagophycus* disappeared from the area protected and have never grown again. Constant motion is a necessity in the growth of the Laminariaceae, as Drew (1910, p. 180) found when he attempted to grow them in aquaria. He did not succeed until he devised apparatus for keeping his young plants in motion. *Chorda* and *Laminaria saccharina* need as little motion as any of the Laminariaceae, but even they need some.

*Floating forms.*—When the majority of the species of the Laminariaceae are torn from their surroundings and tossed about by the waves or carried along by the currents, they gradually sink, being buoyed up to some extent by their expanded blades, but not indefinitely. Some forms, however, have hollow and inflated portions filled with gases, which buoy them up for long periods, and they float when torn away from their attachments. Such are *Pelagophycus*, *Macrocystis*, *Nereocystis*, *Postelsia*, *Ecklonia buccinalis* of the Cape of Good Hope, and *Alaria fistulosa*. These inflations are of advantage to the plant in buoying up the stem and the leaves, so that they may receive the full benefit of the light and of the aerated water. When the part torn away bears the sori, this buoyancy may also assist in the dissemination of the reproductive bodies. But in *Macrocystis* and *Alaria* the fruiting portions are not torn away with the buoyant part, so that this can not be the case in those genera.

The floating kelps (or the buoyant portions of them) are often met by vessels floating in widespread masses, often many acres across, as well as singly. In crossing Bering Sea from St. Michaels to Unalaska I have constantly seen, day after day, stems of *Nereocystis* closely packed together and by the acre. In Unimak Pass, in the eastern Aleutian Islands, I have seen the surface literally covered with the blades of *Alaria fistulosa*. In Wrangell Narrows, in southeastern Alaska, I have seen great quantities of both species borne along by the current. The approach of land is heralded by these floating weeds. In the days of the Manila Galleon there was a sharp lookout kept at about the proper time on the eastward trip for the first Porra (floating *Pelagophycus*); and when it was discovered there was solemn mass said and much rejoicing aboard ship, and so regular was the appearance that the longitude was corrected by it and the ship's course was changed to the southward (cf. Setchell, 1908, p. 130).

*Duration of life and seasons.*—Comparatively little is known about the duration of life among the Laminariaceae. There are certainly annuals, and some of our largest species are among these, and some are perennials. In the case of the latter species we do not know whether their life continues for few or many years. The shortest

lived Laminariæ known to me are *Laminaria saccharina* f. *Phyllitis* and *L. ephemera*. The life of any individual of each of these species is probably of only a few months' duration (cf. Setchell, 1901, p. 122). This is similar to the ordinary annual plants of temperate zones. As annuals having a life of a full year or somewhat over perhaps are to be reckoned *Laminaria longicruris*, *L. stenophylla*, *L. intermedia* (?), *Costaria costata*, *Cymathære triplicata*, *Postelsia palmaeformis*, *Nereocystis luetkeana*, and *Pelagophycus porra*. Not all of these are certain, but some are, and the general appearance, disappearance, and reappearance seems to favor this view in the case of the others. The rest of the Laminariaceæ seem to be perennial, but this matter still demands careful investigation. Some kelps have definite rings showing in the cross section of an older stipe; and while these rings are due to deposits of pigment rather than differences of structure (as in Dicotyledonous woody perennials), there is a theory that they correspond to the annual rings of shrubs and trees among Exogens (cf. Ruprecht, 1848, p. 61). In the treelike Lessoniæ of the Falkland Islands the resemblance in size and "rings" is so great that their trunks cast ashore resemble drift logs to such an extent that Hooker (1845, p. 152) states that they have been collected for fuel by those who did not realize their incombustible nature. Many of our stouter Laminariaceæ show such "rings of growth," but no careful observation has as yet demonstrated their true nature.

The sori are generally produced in late summer and autumn, maturing in winter. Young plants are found in winter and spring, as a rule, but sporadic "sporelings" are often found long "out of season." At maturity, if annual, the whole plant seems to weaken and be readily torn away from its place of attachment, but if perennial only the sorus-bearing portion wears away or disintegrates.

This matter of the season of fructification and the manner of its production becomes one of importance in connection with any proposition to harvest extensively the existing growth. In *Nereocystis* and *Pelagophycus*, for example, the plant is annual and bears the sori on the blades, which are terminal. If the plant is removed at any stage prior to the discharge of the zoospores, it can not reproduce, and if all the plants of a season were removed there would result extermination. However, as said above, sporadic sporelings appear at various seasons, so that absolute extermination is improbable, or even great decrease of numbers. In *Macrocystis*, the sori are situated, for the most part at any rate, on leaves low down on the plant toward the base, so that the greater portion of the upper part of the plant may be removed and still the plant grow. Being perennial, it will also regenerate from the basal portions and grow again, so that the harvesting of *Macrocystis* is likely to have little effect toward decrease or, particularly, extermination. Conditions of fruiting and regeneration in the Alaskan *Alaria fistulosa*, the fourth species of kelp on our coast growing gregariously in fairly deep water, are similar to those of *Macrocystis*, though differing in detail. The sori are on sporophylls, near the base of the plant, several fathoms deep, from which the long blade (up to 25 meters in length) rises and floats along the surface.

The growth of kelps, so far as rate is concerned, has never been carefully and accurately determined. That it must be rapid appears

certain from the growth made in one season by the annual kelps, such as *Nereocystis* (cf. Frye, 1906, p. 143, and Setchell, 1908, p. 127) and *Pelagophycus* (cf. Setchell, loc. cit.). That a kelp may make a growth of 45 meters or more in one season is certain, and that all kelps, even perennials, probably reach a fair proportion of their growth in four to six months, seems equally certain. Further study as to this matter for the sake of insuring exactness is very much needed. *Macrocystis* is one of the species needing careful study from this point of view, for in many places it forms a thick belt some distance from shore, which acts as a sort of breakwater and protects the adjacent shore from erosion. The entire removal of such protection may be attended with unpleasant, perhaps seriously injurious, results. No data are at present before us for estimating how soon after the removal the upper portions may grow again.

*Regeneration.*—There are several forms of regeneration to be found among the Laminariaceae. For convenience, the processes may be divided between physiological regeneration and restorative regeneration (cf. Setchell, 1905, p. 140 et seq.), and also the first may again be subdivided into continuous physiological regeneration and periodic physiological regeneration.

All kelps have physiological regeneration of the blade to a greater or less degree. The blade disintegrates and is worn away above and is renewed at the base at the same time that the stipe is increasing in length at its upper end. This process is continuous during the season of growth and is comparable to the wearing away of the skin in animals and its constant renewal and to the wearing away or shedding of the bark of trees and shrubs and its constant replacement.

Many perennial kelps show a noticeable periodic physiological regeneration, while others do not. In marked cases it is known as the renewal of the blade, the old blade appearing to be cast off by the new one. This happens after a period of rest, usually taking place in winter, when the renewed active growth, occurring in the springtime as a rule, causes the blade of the season to grow rapidly. A noticeable constriction occurs at the base of the old blade, which is further to be distinguished from the new one by its texture, thickness, color, etc. It is most marked in the digitate species of *Laminaria*, such as *L. hyperborea*, *L. andersonii*, and related species, but is sometimes very noticeable in the species with undivided blades, e. g., in *L. solidungula*, *L. rodriguezii*, *L. farlowii*, and *L. sinclairii*. It has been seen also in *Agarum* and in species of *Alaria*. In investigating the Laminariaceae of the Pacific coast of North America I have studied it in *L. sinclairii*, *L. farlowii*, and *L. andersonii* (cf. Setchell, 1905). In each of these cases I have found that this regeneration proceeds from the inner tissues only, the cortical tissues being ruptured at the transition place at the very beginning of the process.

Restorative regeneration, both as to restitution and compensation, takes place in many kelps, and may take place in all, as seems likely, if the injury happens to an actively growing part or at the proper season. As a result, all sorts of abnormal forms result. When a longitudinal split passes through the transition place sufficiently early in the growing season a bifurcate form results. Such forms have often been described as varieties. Such forms are known in

several of the digitate *Laminariae*, and these species are particularly susceptible to this form of injury. They split the meristematic tissues at the transition place into two distinct longitudinal regions, the wounded surfaces close more or less, and the ordinarily simple stipe becomes forked above, each fork carrying a separate blade, which soon becomes symmetrical, instead of one-sided, at the base. Postels and Ruprecht (1840, p. 10, Pl. XIV) have described such a form of *Laminaria bongardiana*, and a similar form was evidently described as early as 1766 by Gunner and figured by him. Even more remarkable regenerations, after vertical splittings, have been seen in *Alaria* and *Pterygophora*, as described by me elsewhere (1905, pp. 149, 150). In these the wounded inner margins are so far regenerated as to produce sporophylls, thus completing the symmetry of each half to a remarkable degree. *Eisenia arborea* frequently has one arm split and, consequently, forked. *Nereocystis* and *Pelagophycus* specimens are known with two bulbs, evidently resulting in the same fashion. *Postelsia* is known with lateral as well as terminal clusters of blades. Other sorts of mutilations than through vertical splitting seem less likely to be succeeded by regenerative growth. A great variety, however, is to be found in *Laminaria sinclairii*, where they have been carefully studied (cf. Setchell, 1905). Transverse rupture of the stipe is followed by the growth of a new blade whose meristematic tissue is at its base, and from this additions to the stipe are made. Tangential and obliquely vertical injuries are followed by new outgrowths on the side of the stipe, a blade at right angles or oblique to the stipe, and ultimately a new portion of stipe at right angles or oblique to it. This results in "branching" forms of *Laminaria sinclairii*, which are very puzzling until their origin is understood. In *Laminaria sinclairii*, at least, the outermost tissues take no part in the restorative regeneration. As in the periodic physiological regeneration, it is only the inner tissues of the stipe which have the power of regenerative growth.

Whether the so-called "trilaminar" forms are also the result of regeneration or not is uncertain. In these forms a complete, or usually a partial, blade springs at right angles from one surface of the original blade. If this is fairly complete and well developed, it gives the blade the appearance of consisting of three blades joined together. Although such forms are not infrequently met with, their origin is as yet uncertain. The best-known cases of restorative regeneration have arisen in connection with the stipe or transition-place.

#### SPECIAL MORPHOLOGY AND CLASSIFICATION.

It has seemed best to combine the accounts of special morphology and classification, and to include brief accounts of all the species of *Laminariaceae* known in North America in their proper sequence and under their proper subfamilies and tribes.

#### Family LAMINARIACEAE.

##### Subfamily 1.—LAMINARIOIDEAE.

Stipe present, at least in early stages, persistent or evanescent, neither branched (except in Nos. 3, 4, and 9) nor provided with

leaflets; blade plane, simple, or digitately divided (becoming compound only in Nos. 3, 4, and 9); paraphyses provided with hyaline appendages, except in Tribe 1.

### Tribe 1.—PHYLLARIEAE.

Holdfast discoid or bullate, never of *branched* hapteres; blade plane; paraphyses destitute of hyaline appendages.

#### 1. *Phyllaria* (Le Jolis) Gobi.

### Tribe 2.—LAMINARIEAE.

Holdfast discoid or of branched hapteres; blade plane, bullate within margins or ruffled, never with longitudinal folds, ribs, or perforations; paraphyses with hyaline appendages.

#### 2. *Laminaria* Lamour.

### Tribe 3.—HEDOPHYLLEAE.

Holdfast of branching hapteres; stipe present in early stages, persistent or vanishing, falsely branched above (except in *Hedophyllum sessile*); paraphyses with hyaline appendages.

#### 1. *Bases of blade not auriculate.*

#### 3. *Hedophyllum* Setchell.

#### 2. *Bases of blade auriculate.*

#### 4. *Arthrothamnus* Rupr.

### Tribe 4.—AGAREAE.

Holdfast discoid or of branched hapteres; stipe and blade simple (or compound in No. 9), provided with longitudinal folds, ribs, or perforations; paraphyses with hyaline appendages.

#### 1. *Blade with a single, broad, shallow meridional fold.*

#### 5. *Pleurophycus* Setchell and Saunders.

#### 2. *Blade with several (3) longitudinal folds.*

#### 6. *Cymathaere* J. Ag.

#### 3. *Blade with several (4-5) longitudinal ribs projecting only on one or other surface.*

#### 7. *Costaria* Grev.

#### 4. *Blade with a broad midrib and more or less perforated.*

8. *Agarum* (Bory) P. & R.

5. *Blade early divided, destitute of midrib, perforate; stipe branched.*

9. *Thalassiophyllum* P. & R.

## Subfamily 2.—LESSONIOIDEAE.

Stipe persistent, elongating, branched dichotomously or sympodially, through repeated longitudinal splittings at the transition place; paraphyses with hyaline appendages.

## Tribe 5.—LESSONIEAE.

Branching of the stipe regularly dichotomously throughout, or nearly so.

1. *Stipe erect, solid, with or without a definite trunk.*

10. *Lessonia* Bory.

2. *Stipe flattened, prostrate, rooting.*

11. *Dictyoneuron* Rupr.

3. *Lower part of stipe forming a hollow trunk bearing a bunch of short branches and blades at its summit.*

- (f) *Trunk cylindrical, hollow, and of same diameter throughout.*

12. *Postelsia* Rupr.

- (b) *Trunk solid below, hollow above, constricted just below the apex and then expanded into a large hollow bulb.*

13. *Nereocystis* P. & R.

## Tribe 6.—MACROCYSTAE.

Branching of the stipe at first regularly dichotomous, but soon becoming unilateral and sympodial.

1. *Stipe solid, slender, soon sympodial, bearing numerous blades which bear bladders at their bases.*

14. *Macrocystis* Ag.

2. *Stipe forming a trunk solid below, hollow above, constricted just below the apex and then expanding into a large hollow sphere, bearing two branches which branch at first dichotomously but soon sympodially.*

15. *Pelagophycus* Aresch.

## Subfamily 3.—LESSONIOPSOIDEAE.

Stipe increasing in complexity in two ways: (1) By dichotomous splitting at the transition-place (Lessonioid), and (2) by outgrowths



(sporophylls) on the margins of the transition-place on the side toward the stipe (Alarioid); paraphyses with hyaline appendages.

Tribe 7.—LESSONIOPSEAE.

Characters of the subfamily.

16. *Lessoniopsis* Reinke.

Subfamily 4.—ALARIOIDEAE.

Complexity of the front arising by outgrowths from the margins of the transition place and usually functioning as sporophylls; paraphyses with hyaline appendages.

Tribe 8.—ALARIEAE.

Outgrowths (leaflets or sporophylls) arising on the stipe side of the transition place only; no bladders.

1. *Sporophylls of continuous growth; blade with thickened meridional region but no distinct midrib.*

17. *Pterygophora* Rupr.

2. *Sporophylls of limited growth; blade with distinct midrib.*

18. *Alaria* Grev.

Tribe 9.—ECKLONIEAE.

Outgrowths (leaflets or sporophylls) arising on the blade side of the transition place only; no bladders.

19. *Eisenia* Aresch.

Tribe 10.—EGREGIEAE.

Outgrowths (leaflets or sporophylls) arising on both the stipe side and on the blade side of the transition place; some of them provided with bladders.

20. *Egregia* Aresch.

Family LAMINARIACEAE.

Complex plants having a brown coloring matter (phycophaein) in addition to the chlorophyll, thus appearing of different shades of brown and olive green to almost black; having the plant body differentiated (at least when young) into holdfast, stipe, and blade; having zoospores with laterally attached flagella, contained in unilocular zoosporangia ("gametangia" of Drew), which, intermingled with unicellular paraphyses, are combined into broad patches or sori, usually situated on the blade, but in some species on special leaflets (sporophylls), or even on the flattened, often also ruffled, stipe.

The family of the Laminariaceae, or kelps, comprises 25 or 26 genera and 80 to 90 species. On the coasts of the United States (including Alaska) full 19 genera are to be found and about 50 species. The family is fairly compact, and is related most nearly to the Chordaceae, and through them probably to the Punctariaceae. Many or all of the kelps are large in size, i. e., for algae, and some of them grow to be very long and of fair bulk. In all structure they are complex, having well-developed assimilatory, mechanical, and conducting systems of tissues. In these they present a complexity and grade of differentiation of distinctly higher type than found among other algae and approaching, especially in the sieve tubes of the more complex forms, the types of tissues in land plants of the flowering-plant class.

The Laminariaceae are abundant on both the east and the west coasts of North America. On the east coast they are most abundant in Baffin Bay and on the coast of Labrador, decreasing in numbers, both of species and individuals, to the southward. They are not found much to the southward of New Jersey on the east coast. The east coast possesses about 9 species distributed through 4 genera. The west coast of North America has the richest kelp flora, both as to variety of genera and species, of any region inhabited by the Laminariaceae. From Bering Sea to Magdalena Bay they abound, decreasing, as usual, toward the south. On this long strip of coast are to be found over 80 species distributed through at least 18 genera, there being only 1 genus of the Atlantic coast not represented on the Pacific coast. The only coast approximating the number of genera and species of Laminariaceae found on the Pacific coast of North America is the eastern (i. e., northeastern) coast of Asia, but this rich district lacks 7 genera of those found on the North American side.

As has been mentioned above, it has been found desirable to divide the family into 4 subfamilies, the Laminarioideae, the Lessonioidae, the Alarioideae, and the Lessoniopsoideae, in accordance with the varying methods of increasing the complexity of the frond, noted particularly in the postembryonal stages and originating at the transition place. These types of the subfamilies are clearly distinct from one another and are further divided into tribes.

#### Subfamily 1.—LAMINARIOIDEAE.

The members of this subfamily are distinguished from those of the other subfamilies by their simplicity. They consist, for the most part, of plants having a holdfast, single stipe, and blade. The stipe may disappear early and its place be taken by the arms (or pseudostipes), arising from the thickened basal margins of the blade (e. g., *Hedophyllum subsessile*, *Thalassiophyllum*, and *Arthrothamnus*), but this exceptional process is decidedly unlike the regular and repeated process of splitting at the transition place found in the Lessonioidae. The blade may be plane, ruffled, bullate, perforate, or ribbed, but, nevertheless, compared with the complex fronds of the members of the other subfamilies, they are still simple. There is, however, enough variety in the fronds to warrant their separation into four tribes—the Phyllarieae, the Laminarieae, the Hedophylleae, and the Agareae.

The members of this subfamily are nearly all to be found in the boreal, north temperate, and north subtropical waters. Two species of *Laminaria* are found on the southern and western shores of Africa and one species (*Laminaria himantophylla* P. & R.) is credited to the extratropical shores of South America, but has never been seen since its description.

### Tribe 1.—PHYLLARIEAE.

The members of this tribe have holdfast root, stipe, and blade, all simple, with the blade plane, but they are to be distinguished from other members of the Laminarioideae by the fact that they lack the hyaline appendages to the paraphyses found in all other members. not only of this subfamily but of the family, so far as is known. It may be that they should be separated as a special subfamily, but, fundamental as is this difference, it seems best to keep them in the Laminarioideae. They form a link in this, and in a certain simplicity of internal structure, between *Laminaria* and *Chorda* (which also lacks hyaline appendages).

There are only two genera in the Phyllarieae—*Phyllaria* and *Sacchoriza*. The latter genus, containing one species, is found only on the southwestern shores of Europe. It is a large plant, like a *Phyllaria* in its early stages, but developing a hollow bulblike holdfast, up to a foot in diameter and covered with hapteres, a broad, finally ruffled stipe, and a large broad blade digitately split into many segments. A full-grown, full-sized plant, when fresh, spreads 7 feet across and weighs so much that a man finds it a considerable load to carry. It is an annual plant. (cf. Barber, 1889.)

#### 1. *Phyllaria* (Le Jolis) Gobi.

Root discoid or with a few rudimentary hapteres; stipe cylindrical below, flattened above; blade simple or digitately divided, plane; sori broad; on both sides of the blade; paraphyses without hyaline appendages.

A genus of three or four species, as usually recognized, two of which are confined to the western Mediterranean Sea. 1. *P. dermatodea* (de la Pyl.) Gobi. is the only species within our limits. It is a plant more or less common on the Atlantic coast from Cape Cod northward. It occurs also in northern Europe.

### Tribe 2.—LAMINARIEAE.

The members of the tribe possess holdfast, stipe, and blade in well-developed form, even in the adult stages. The holdfast is discoid (*L. solidungula*), in the form of one or more regular or irregular whorls of more or less dichotomous hapteres, or in the form of a branched and creeping rhizome. The stipe is simple, cylindrical, or more or less flattened, with trumpet hyphae in the medulla, and with or without mucilage ducts; the transition place is plane and unmodified; the blade is single, simple, or palmately deeply split, and plane or with a row of bullae on either side of the meridional region, with the borders more or less ruffled. The sori occur on the blade in the form of extended patches. In most species they may cover both

surfaces, especially of the meridional region, or they may be present as rounded or irregular shaped patches. In some species they form longitudinal vittae; in others, hieroglyphic shaped patches over the central part of the blade; in others, distinct rounded patches on the sides of the blade (leaving the meridional portion free) when they are either basal (*L. rodriguezii*) or in a fairly regular series (species of *Kjellmanniella*). The paraphyses are always provided with a terminal hyaline appendage. There are at most two genera in this group, viz, *Laminaria* and *Kjellmanniella*. The former consists of many species widely distributed in the frigid and temperate waters of the northern hemisphere and represented scantily in the south Atlantic and south Pacific (?) waters. The latter is restricted to a few species of Japanese waters, and is little known at present (cf. Miyabe, 1902). It seems to be a link between the *Laminarieae* and the *Agareae*.

## 2. *Laminaria* Lamour.

Holdfast of branched hapteres, rarely disk shaped; stipe simple, well developed, cylindrical or flattened above, solid or hollow, with trumpet hyphae, with or without mucilage ducts, with or without annual (?) rings; transition-place plane, undivided; blade simple or palmately more or less deeply split, plane, or with intramarginal bullae and marginal ruffles, with or without mucilage ducts; sori diffuse or circumscribed covering both surfaces wholly or partially, at times vittate or rounded; paraphyses with well-developed hyaline appendages.

The genus *Laminaria*, as at present circumscribed (i. e., excluding *Kjellmannia*), contains about 35 described species distributed on the northern and middle shores of Europe, Asia, and both coasts of North America. Two species occur in southwestern Africa and one (*L. himantophylla*) is reported from the extra tropical shores of South America. Some of the species need careful revision. The species are separated as to whether the blade is split or entire and as to the presence or absence of mucilage ducts in the stipe and in the blade. In accordance with these characters the North American species may be arranged as follows:

### Section I.—SACCHARINAE.

Blade simple, or only occasionally split.

A. Mucilage ducts absent from both stipe and blade.

1. *L. agardhii* Kjellm.

B. Mucilage ducts absent from the stipe, present in the blade.

a. Blade plane, ruffled, or bullate, but not longitudinally wrinkled.

1. No creeping rhizome present.

\* Stipe solid, cylindrical.

2. *L. saccharina* (L.) Lamour.

\*\* Stipe solid, flattened above.

3. *L. complanata* (S. & G.) Setchell.

\*\*\* Stipe cylindrical, hollow above.

4. *L. longicruris* de la Pyl.

2. Creeping rhizome present.

5. *L. longipes* Bory.

b. Blade not plane, ruffled, or bullate, but coarsely and longitudinally wrinkled.

6. *L. farlowii* Setchell.

c. Mucilage ducts present in both stipe and blade.

a. Holdfast discoid.

7. *L. solidungula* J. Ag.

b. Holdfast of branched hapteres, no rhizome.

\* Stipe short in proportion to the blade.

8. *L. cuneifolia* J. Ag.

\*\* Stipe long in proportion to the blade.

9. *L. groenlandica* Rosenw.

c. Holdfast of branching hapteres, creeping rhizome present.

10. *L. sinclairii* (Harv.) Farlow.

## Section II.—DIGITATAE.

Blade vertically split into few or many segments.

A. Mucilage ducts absent from both stipe and blade.

11. *L. ephemera* Setchell.

B. Mucilage ducts absent from the stipe, present in the blade.

a. Stipe stout, rigid, flattened above.

12. *L. digitata* (L.) Lamour.

b. Stipe cylindrical or compressed, weak.

\* Blade broad, often cucullate, split, usually, into few to several broad segments or entire.

13. *L. cucullata* (Le Jolis) Foslie.

\*\* Blade narrow, split into few to several narrow segments.

14. *L. stenophylla* (Harv.) J. Ag.

c. Mucilage ducts present in both stipe and blade.

a. Stipe cylindrical or only slightly compressed toward the apex.

\* Mucilage ducts of the stipe just below the surface, even at the base.

15. *L. dentigera* Kjellm.

\*\* Mucilage ducts of the stipe, at least at the base, deep (about halfway between the surface and the center).

16. *L. andersonii* Farlow.b. Stipe flattened from shortly above the base, upwards.  
Blade plane, without bullae.17. *L. platymeris* de la Pyl.

\*\*. Blade with a row of prominent bullae within each margin.

18. *L. bullata* Kjellm.

## Section I.—SACCHARINAE.

Blade simple, or only exceptionally split into one or two comparatively broad divisions, perfectly plane or with intramarginal bullae and marginal ruffles. Sori more or less covering the surfaces of the blade or circumscribed into rounded patches and at times occupying only the meridional region.

1. *L. agardhii* Kjellm. is a species with longer or shorter stipe branched hapteres without a rhizome and destitute of mucilage ducts in both stipe and blade. It occurs on the Atlantic coast of North America, from New Jersey northward. It is also found in Greenland, Spitzbergen, and the Murman and Kara Seas.
2. *L. saccharina* (L.) Lamour. has mucilage ducts in the blade, but none in the stipe. Otherwise it varies as the preceding species does. On the Atlantic coast of North America it extends from Cape Cod northward and on the Pacific coast from Cape Flattery northward.
3. *L. complanata* (S. & G.) comb. nov. is the *L. saccharina* f. *complanata* of Setchell and Gardner, *Algae of northwestern America*, p. 26, 1903, and of Gardner, in Collins, Holden, and Setchell, *Phyc. Bor. Am., Fasc. D: No. LXXXVII, 1905 (Exs.)*. It is to be distinguished from other species of the *Saccharina* section by its very much flattened stipe. It is known as yet only from the region of Puget Sound.
4. *L. longicuris* de la Pyl. is a species of the Atlantic coasts of North America, from Long Island Sound northward. It is to be distinguished by having the upper half, or more, of the stipe hollow.

5. *L. longipes* Bory is a species of the Bering and Ochotsk Seas. It lacks mucilage ducts in both stipe and blade, and has creeping rhizomes, which give off hapteres and new fronds. It is to be distinguished from *L. sinclairii* by its absolute lack of mucilage ducts.
6. *L. farlowii* Setchell occurs on the coasts of southern and middle California, and is to be recognized by its rather thick, coriaceous, coarsely longitudinally wrinkled blade.
7. *L. solidungula* J. Ag. is a species of the coasts of Greenland, Spitzbergen, and of the Kara, Murman, and Siberian Seas. It probably lies entirely without our limits, but has been reported, probably erroneously, from the Alaskan shores. It is to be distinguished by its broad and massive discoid holdfast.
8. *L. cuneifolia* J. Ag. is another species not certainly known to occur on the coast of the United States. It has been reported from Alaska, but the report needs confirmation. It resembles the forms of *L. saccharina* and *L. agardhii*, but has mucilage ducts in both stipe and blade. It is to be distinguished from *L. groenlandica* by its stipe being always much shorter than the blade.
9. *L. groenlandica* Rosenv. is very similar to *L. cuneifolia*, except that its stipe is long in proportion to the blade. Thus far, it is reported only from Greenland (both east and west coasts). It may at some time be found on the northern New England coast.
10. *L. sinclairii* (Harv.) Farlow is very common on the Pacific coast of North America from just above Point Conception in California to the southern end of Vancouver Island. Its creeping rhizomes and the presence of mucilage ducts in both stipe and blade easily separate this species. Its long, narrow, strap-shaped fronds also distinguish it from all except *L. longipes*.

#### Section II.—DIGITATAE.

Blade vertically split into few or many segments. While in general there is no difficulty in recognizing the members of the digitate group of species of *Laminaria*, we do find entire forms occurring in the form-variations of each and every species under it. For the most part such forms are broad, plainly indicating their affinities; in some species, notably in *L. bullata* and *L. ephemera*, they may be very narrow, resembling thus the members of the *Saccharina* section very closely. On the other hand, broad (or even narrower) forms of *L. farlowii* may be occasionally split into one or two divisions. Except for the two species just mentioned, there is little difficulty in deciding to which section of the genus to refer any given plant.

11. *L. ephemera* Setchell is a delicate species with or without digitately split blade, absolutely devoid of mucilage ducts, and having a discoid holdfast. It has been found near Pacific Grove, Cal., and at Port Renfrew, on the southern coast of Vancouver Island, British Columbia.
12. *L. digitata* (L.) Edm. is a somewhat variable species, with mucilage ducts in the blade, but lacking them in the stipe, and having the stipe rigid, stout, but decidedly flattened above. It occurs in several forms on the Atlantic coast from Long Island Sound northward. The plants of this species are commonly known as "Devil's Aprons," and in Scotland as "Tangle."

13. *L. cucullata* (Le Jolis) Foslie is a plant of the digitate section, with a cylindrical or slightly flattened and weak stipe. It usually has a broad blade, ovate or cordate at the base, and split into few to several segments. It inhabits quieter waters on the southern coasts of New England.
14. *L. stenophylla* (Harv.) J. Ag. has the stipe of the last, but the blade is narrow, cuneate, and split into a number of narrow segments. It grows on rocks and mussel shells in exposed places on the coast of New England north of Cape Cod.
15. *L. dentigera* Kjellm. is a species of the Bering Sea and the Aleutian Islands. It has a stout stipe, only slightly compressed above, and with the mucilage ducts, even in old specimens, very little under the surface. It may prove to be only a high northern variety of the next.
16. *L. andersonii* Farlow is very similar to the last, but has the mucilage ducts, in the lower portions of the stipe at least, situated about half way between the periphery and the center. It is found on the Pacific coast from somewhere below Monterey, Cal., to Puget Sound.
17. *L. platymeris* de la Pyl. is a species long known on the coast of New England. I here use it to include a number of described species, viz., *L. bongardiana* P. & R., *L. fissilis* J. Ag., *L. nigripes* J. Ag., *L. atrofulva* J. Ag., *Hafgygia rupprehti* Aresch., *L. discolor* Strömf., and *L. taeniata* P. & R. All these described species seem to agree in having a plane, digitate blade of varied shape and degree of splitting and a stipe, decidedly flattened from just above the base. From the succeeding species this species is to be distinguished chiefly by the absence of longitudinal rows of transverse bullae with each margin of the blade. As thus understood, it is circumpolar and to be found both in the north Atlantic and the north Pacific Oceans. On the Atlantic coast it ranges from Cape Cod northward and on the Pacific coast its southern limit is the Strait of Juan de Fuca. It is found on the northern shores of Asia, of Europe, and on those of Spitzbergen and of Greenland.
18. *L. bullata* Kjellm. is a very variable species in form and size, occurring from simple Saccharina forms with entire blade to broad deeply split digitate forms with few to several divisions. It is to be distinguished from the last by the row of large, prominent, transverse bullae within each margin of the blade. Its distribution is entirely north Pacific, extending from the Strait of Juan de Fuca north into Bering Sea.

### Tribe 2.—HEDOPHYLLAE.

Stipe present only in very young plants, later disappearing or remaining short and obscure; blade plane (or irregularly bullate), soon becoming sessile and more or less decumbent, thickened, and emitting hapteres, either scattered or in whorls; meridional region in most species wearing away, leaving the thickened (and sometimes auriculate) basal margins separated from one another, to grow or into simple or, in turn, dichotomously falsely branched fronds.

ap-  
olade



### 3. *Hedophyllum* Setchell.

Plants at first like *Laminariae* of the digitate section, with holdfasts, very short stipes, and broad plane blades; meridional region at times remaining intact and splitting vertically (*H. sessile*), at other times wearing away to the very base leaving the margins to continue the growth (*H. subsessile* and *H. spirale*), as broader or narrower blades, plane, cucullate, or spirally twisted but without basal auricles; sori basal, irregular in shape.

A genus, to which there are at present reckoned three species, all distinguished from other kelps by having the base of the blade more or less decumbent and without auricles. It may be divided into two sections, viz, (1) having the hapteres arising irregularly from the decumbent base (cf. Setchell, 1905, p. 12, figs. 3, 4) and the meridional region persistent, and (2) having the hapteres arising from the bases of the blade in distant whorls or absent, and the meridional region wearing away even to the base (cf. Setchell and Gardner, 1903, pl. 20, fig. 31). The genus was founded on the plant (*H. sessile* (Ag.) Setchell), which comprises the first section, which is much simpler in its morphology and development than the other two. In the other two species, viz, *H. subsessile* (Aresch.) Setchell and *H. spirale* Yendo, the meridional region wears away almost to the base, where the portions left thicken into two arms (one on each side of the original short stipe), which seem like branches of the stipe, each bearing a partial blade. The short stipe disappears early in *H. sessile*, later, in all probability in *H. subsessile*, and seems persistent in *H. spirale*. The last two species resemble *Arthrothamnus*, but in the species of that genus the partial blades are again eroded in the central region, which process is repeated several times (cf. Yendo, 1903, pp. 168 et seq., pl. 6, figs. 9-11), the partial blades are narrow, strap-shaped, and provided with prominent auricles at the base.

The genus *Hedophyllum* is not entirely satisfactory in its characters. Between *H. sessile* and *H. spirale*, there is a very considerable divergence only partially harmonized by *H. subsessile*. More species, or more stages of development, may be discovered and may lead ultimately to segregation, but it seems best to leave it as it is, for the present.

*Arthrothamnus* Rupr.

Holdfast either primary at the base of the stipe or secondary, in

more or less dense whorls, sheathing the arms (or false branches); true stipe short, simple, flattened; false stipe (thickened bases of the blade) repeatedly dichotomous, prostrate, or erect; blades narrow, strap-shaped, auricled at the base, wearing away in the center, thickening into "arms" at the base, each new blade arising from the more or less eroded stipe (or arms) by a cylindrical process; sori—?

The genus *Arthrothamnus* was founded by Ruprecht (1848, p. 67) to receive *A. boryana*, a plant of the Bory Islands, unlike any other kelp. In 1881, Setchell and Gardner suggested it to receive also the *Arthrothamnus* of Grmelin (1768, p. 201, pl. 29, fig. 2). J. G. Agardh (1867, p. 28) added the *Arthrothamnus* of Bory (cf. above) and *A. boryana* P. & R. (cf. above under *Hedophyllum subsessile*).

These two last species, however, are to be rejected from the

genus, which still retains the two species assigned to it by Ruprecht. Much more needs to be known concerning these rare plants of the Kurile Islands and of Bering Island. Yendo (1903, pp. 168-169, Pl. VI, figs. 9-11) has added much to our knowledge of the development and made it clear that, in the present stage of our knowledge, it is best to retain the genus near *Hedophyllum*, at least near to *H. subsessile* and *H. spirale*, but also to note that in the continued splitting of the transition place, it approximates to the *Lessonioidae*. Neither of the species has yet been found within our territory, but they are both fairly likely to occur on the Western Aleutian Islands at least. Hence, this brief mention has been made.

### Tribe 3.—AGAREAE.

Stipe persistent, elongating (except in *Thalassiophyllum*); blades longitudinally plicate or ribbed, plane, bullate, or perforate, in some genera with scrolls at the base.

The Agareae vary much in character, but in no case is the blade absolutely plane. There are longitudinal folds or ribs, or else perforations. In some cases ribs and perforations or bullae are combined. The genera are all of the Northern Hemisphere and, with one exception, are to be found in the North Pacific. All of the 5 genera and all of their species are to be found on the western and northwestern coasts of North America. I am uncertain as to whether the *Laminaria gyrata* Kjellman, which Miyabe has made the type of his new genus *Kjellmanniella* (1902, p. 1, pls. 15-17 [nomina nuda?]), is to be included under this tribe or under the *Laminarieae*. It has certain resemblances in having an almost midriblike meridional region (cf. Kjellman, 1892, and Miyabe, loc. cit.) and may have to be placed near to *Pleurophycus*, though by no means identical with it. I have not had the opportunity of examining any specimens. Some one of the species may yet be found on the coasts of Alaska.

#### 5. *Pleurophycus* Setchell and Saunders.

Holdfast of branching hapteres; stipe simple, elongating; blade long, undivided, with a single median, longitudinal, broad, shallow, fold, and with broad margins ruffled; sori narrow, on both surfaces of median fold.

This genus is more like a member of the *Laminarieae* than any other of this tribe, unless it may be the *Kjellmanniella* of Miyabe. *Cymathaere* comes fairly close, but *Pleurophycus* seems rather nearer. It has the narrow meridional region slightly indented on one surface and slightly raised on the other, thus forming a rather broad but shallow fold which is not noticeably thickened.

1. *P. Gardneri* Setchell and Saunders is the only species. It is a large plant, looking much like a species of *Laminaria* and ranging along the Pacific coast from Puget Sound to Yakutat Bay.

#### 6. *Cymathaere* J. Ag.

Holdfast discoid, or with inconspicuous rudimentary simple hapteres; stipe short, flattened, persistent, with mucilage ducts; blade

long, narrow, longitudinally grooved or loosely folded in the meridional region, with abundant large mucilage ducts; sori broad on both surfaces.

A genus of one species on the northwest coast of North America and in Bering Sea, approaching *Laminaria*, but distinguished by the longitudinal furrows and slight ridges in the meridional region. Griggs (1907, p. 89 et seq.) tries to demonstrate that it "branched off the main phylum of the *Laminariaceae*" early. He is led to this by his belief that *Cymathaere* lacks hyaline appendages to the paraphyses and of well-developed mucilage ducts in the blade. Both of these, however, as I have demonstrated to my own complete satisfaction, are present in very characteristic fashion. He also bases part of his argument on the presence of a discoid holdfast, "poor development of pith web," and long persistence of the one-layered blade in juvenile plants. The "pith web," however, seems as well developed as in some other characteristic *Laminariaceae*, and the almost (but not quite) simple disk of the holdfast with its rudimentary hapteres, seems more like degeneration than survival of primitive characteristics in an arrested form. My own opinion is that it is more complex and of later evolution than most (or even all) of the *Laminariaceae*, but sharing with *Pleurophycus* and *Costaria* a position among the simpler *Agareae*.

1. *C. triplicata* (P. & R.) J. Ag., the type and only species, is readily told by the three more or less deep longitudinal folds in the meridional region and its discoid holdfast. It occurs on the Pacific coast from the Strait of Juan de Fuca into the Bering Sea.

#### 7. *Costaria* Grev.

Holdfast of branched hapteres; stipe short, soon flattened, destitute of mucilage ducts; blade with longitudinal ribs, projecting on one side only and alternating on the two surfaces, bullate and often also perforate, destitute of mucilage ducts; sori broad.

A genus of only one well-defined species apparently, in spite of attempts to distinguish more. Confined to the northern portion of the Pacific Ocean. The bullosity of the blade and the well-defined longitudinal ribs, each confined to one surface and alternating in position, clearly mark off this genus from *Cymathaere* from which it is also to be distinguished by the branching hapteres of the holdfast.

1. *C. costata* (Turn.) Saunders is distributed along the Pacific coast of North America from somewhere below Monterey to Bering Sea. It seems necessary, under the Vienna Code, to use the name of Turner for this species and abandon the familiar name of *C. turneri* P. & R., so long in use.

#### 8. *Agarum* (Bory) P. & R.

Holdfast of branched hapteres; stipe cylindrical or flattened, elongating; blade with broad percurrent midrib and perforated margins; sorus broad.

The genus *Agarum* was refounded and restricted to its present usage by Postels and Ruprecht (1840, p. 11). I have included in this account two species, the one, *A. cribrorum* Bory, having the blade

unrolling from two scrolls at the base and with distinct cylindrical stipe, the other, *A. fimbriatum* Harv., destitute of these scrolls and with the stipe flattened and fimbriate. It may be necessary at some future time to separate this second species under a generic name of its own, but more knowledge of its development is desirable. The two species have the same general aspect, but are different in what may have to be considered essential respects.

1. *A. cribrorum* (Mert.) Bory or "Sea Colander" is the common species of both the north Atlantic and north Pacific coasts of North America. It is to be distinguished from the next by having a cylindrical stipe, two small scrolls at the base of the blade and more regular, as well as coarser, perforations. It ranges from Cape Cod to Greenland on the Atlantic side and on the Pacific side, from about Sitka, Alaska, into the Bering Sea.
2. *A. fimbriatum* Harv. is, so far as known, a fairly local species, being found in abundance in a few localities in the Puget Sound region. However, it has been found, once or twice, cast ashore in southern California, at Santa Barbara and at San Pedro. It has a flattened stipe, coarsely fimbriate, and a thin bullose blade, sparingly perforate, and with finely crisped margins.

### 9. *Thalassiophyllum* P. & R.

Holdfast of stout, dichotomously branched hapteres; primitive stipe short, not elongating, soon buried among the stout hapteres; blade soon eroded to the base and developing two lateral scrolls which unroll from thickened margins and form fan-shaped, spirally-twisted, closely and regularly perforated partial blades; secondary stipes branching adventitiously; no mucilage ducts in stipe or blade; sori in irregular dark-brown patches.

A most interesting, peculiar, and rare genus, inhabiting only the Bering and Ochotsk Seas. In its embryonal stages it is first like a species of *Laminaria*, then like *Agarum cribrorum*. The primitive stipe never elongates, only thickens; very early, however, the juvenile blade, wearing away in the center, leaves the two marginal scrolls, which become perforate and unroll from the outer thickened margin and wear away toward the center (cf. Setchell, 1905, Pl. 13, fig. 12). The plant is now dichotomous and the partial or secondary blades are equal. One now begins to grow more than the other (cf. Setchell, loc. cit., fig. 13), and the plant becomes one sided, the smaller blade remaining nearly stationary or disappearing. The pseudostipe, formed from the thickened base of the margin of the secondary blade, increases in length and branches adventitiously (cf. Rosenthal, 1890, p. 140, Pl. VII, VIII, figs. 33, 34), and the branching frond, with its numerous fan-shaped, perforate, and spirally unfolding secondary blades (cf. Postels and Ruprecht, 1840, Pl. XVIII, XIX) is built up. Were it not for the knowledge we now have (cf. Setchell & Gardner, 1903, p. 267; Yendo, 1903, p. 168; Setchell, 1905, pp. 123-126, Pl. 13, figs. 6-13), we might still doubt the propriety of placing *Thalassiophyllum* next to *Agarum* in the tribe Agareae. With that knowledge, however, such position becomes imperative and all doubts are dispelled.

1. *T. clathrus* (Gmelin) P. & R. is one of the curiosities of the sea. It is restricted to Bering and Ochotsk Sea, where, with its shrubby, branching stem and fan-shaped, spirally coiled, regularly perforate blades, it is a striking plant.

#### Subfamily 2.—LESSONIOIDEAE.

The members of this subfamily are to be distinguished from the members of the subfamily Laminarioideae by their complexity. The stipe is always more or less branched, and not only branched, but branched either dichotomously or sympodially, or both, in a very regular fashion. The branching is brought about by longitudinal splittings in the transition place, and by this method only. It is this which distinguishes the members of the Lessonioideae from the Alarioideae and from the more nearly related Lessoniopsoideae. In the Alarioideae the complexity of the frond over that of the Laminarioideae arises by means of definitely specialized outgrowths, and while the complexity in Lessoniopsoideae arises mainly through longitudinal splitting, it also partially arises through definitely specialized outgrowths. The nature of the split has not been carefully studied as yet. It seems that growth at the transition place becomes, in some manner, localized, ceasing at certain points and becoming more vigorous at others. This applies to growth both as to increase in length and in thickness. The split, then, is in the nature of a wound, similar to the origin of the perforations in *Agarum* (cf. Humphrey, 1886, p. 201), where "there is a gradual decrease in the thickness of the tissue at the tip of a papilla from the time of its beginning until the rupture takes place." As I interpret the various figures of Wells (1910, Pls. XII–XV), very similar processes occur in the various Lessonioideae investigated by him. The different forms differ somewhat in unessential detail, as it seems to me, but on the whole the essentials of the processes are remarkably close, especially considering the differences in texture in the different fronds. I am far from agreeing with the interpretation Wells has placed on the processes especially in the matter of so-called attenuation and weakening. The fact that there is actual rupture, loss of tissue, and regeneration of margins tends to bring the process near to the wearing away of the tissues of the meridional region in *Hedophyllum subsessile*, *H. spirale*, *Arthrothamnus*, *Thalassiophyllum*, and both species of *Eisenia*. In all the cases just mentioned, however, the destruction is far greater, both as to bulk and proportional to what remains. The actual study of the meristematic regions concerned and the physiology of the growth remains yet to be investigated in both the members of the Lessonioideae and the species of Laminarioideae and Alarioideae just mentioned.

No members of this subfamily are to be found in the north Atlantic Ocean nor in the south Atlantic Ocean in a restricted sense, but they are abundant in both the north and south Pacific Oceans, on the coasts of New Zealand, western coast of South America, and western coast of North America, over to the Sea of Ochotsk on the Asiatic side. The Pacific coast of the United States has the most genera and species of any of the coasts inhabited by members of this subfamily, there being 6 genera, each represented by a single species. The coast of South America has 4 species divided between 2 genera, the coasts

of Australasia have 2 genera, each with a single species, while the extreme northeastern coast of Asia has a single species. It has seemed best to divide the subfamily of the *Lessonioidae* into two tribes: (1) *Lessoneae*, where the splitting is equal throughout, resulting in a more or less complete dichotomy; and (2) *Macrocystae*, where the splitting is soon unequal and the result is a one-sided sympodium.

#### Tribe 4.—*LESSONEAE*.

Holdfast of branching hapteres; stipe persistent, remaining short or elongating before splitting; splitting resulting in two equal branches, each with its blade, and repeated in the same fashion, giving rise to a fairly regularly dichotomous stipe, bearing equal blades on its ultimate branches.

The dichotomy in this tribe is as regular as such a method of branching is likely to be. At times, one side of the dichotomy may be suppressed or fail to divide farther, but such cases are not the rule, only the exception, while in the next tribe, after the first one or two divisions, only one side of the dichotomy divides farther.

#### 10. *Lessonia* Bory.

Holdfast of branched hapteres; stipe solid, branching regularly dichotomously, with or without thickened trunk below; blades terminal, splitting longitudinally; sori broad in patches.

This genus is not strictly representative of the United States, or even of North America. A single little-known species is described from the Ochotsk Sea and may at some time be found in the Aleutian Islands or vicinity. The genus reaches its maximum of complexity and size in the Southern Hemisphere, being represented on the west coast of South America, Fuegia, and the Falkland Islands, to reappear in New Zealand. The species of the Falkland Islands are said to be literally arboreous.

1. *L. laminariaeoides* P. & R. is the only representative of this genus in the Northern Hemisphere. It is said to be abundant in the Sea of Ochotsk and may at some time be found on the shores of Alaska.

#### 11. *Dictyoneuron* Rupr.

Holdfast (primary) of branched hapteres, secondary holdfasts similar, formed on the margins of the prostrate stipes; stipes erect or ascending, soon prostrate and rooting, very much flattened and thin, dying off behind and thus vegetatively multiplying; blades reticulated with coarse ribs; sori irregular, broad.

1. *D. californicum* Rupr. is the only species and is found along the Pacific coast from somewhere below Monterey to the southern end of Vancouver Island.

#### 12. *Postelsia* Rupr.

Holdfast of stout branched hapteres; stipe stout, hollow below, bearing at its tip the short, slender, solid dichotomous branches; blades falcate, deeply and regularly longitudinally furrowed on both sides; sori confined to the furrows.

This is a monotypic genus which was described by Ruprecht in "Neue oder unvollständig bekannten Pflanzen aus dem Nördlichen Theile des Stillen Oceans," the date of whose separate issue was 1852. In 1853 it was named Virginia by Areschoug. It is nearly related to *Nereocystis* by its hollow trunk crowned by its tuft of dichotomously split blades. It is one of the most distinct and beautiful of genera.

1. *P. palmaeformis* Rupr. is the fairly well-known "Sea Palm" of the Pacific coast and the only species. It grows on the rocks and only on shores exposed to the heaviest surge. It extends from Point Sur (or below) on the Californian coast to the southern end of Vancouver Island.

### 13. *Nereocystis* P. & R.

Holdfast of branching hapteres; stipe consisting of a long trunk, slender, solid, and cylindrical below, gradually swollen and hollow above, forming a sort of apophysis, then suddenly contracted with a large spherical bladder above the constriction; from the top of bladder the stipe is continued as short, crowded, dichotomous branches, ending in the long narrow leaves which have the appearance of being sessile; sori in broad and elongated patches on both sides of the blades.

1. *N. luetkeana* P. & R. is the only species, ranging from the neighborhood of Point Concepcion on the coast of California to the Shumagin Islands in Alaska. Often found floating and sometimes, especially in Alaska, in broad fields. Growing, it forms beds of greater or less extent in from 10-30 meters of water.

### Tribe 5.—MACROCYSTAE.

Holdfast of branched hapteres; stipe regularly dichotomous for the first few divisions, soon unequally dichotomous, and consequently scorpioidly sympodial; blades of two sorts after the first divisions, the terminal blades alone splitting and to one side; sori in broad patches.

### 14. *Macrocystis* Ag.

Holdfast of whorls of repeatedly dichotomous hapteres, arising from the base of the stipe, which, at times, also becomes flattened and creeping, after the fashion of a rhizome; stipe soon forking *equally once* and possibly twice or thrice, but soon more or less unequally, and finally entirely unilaterally; blade at first splitting equally, but soon with splitting confined to the terminal falcate bladderless blade, the rest entire and provided with a small bladder at the base; sori usually on blades toward the base of the plant.

1. *M. pyrifera* (Turn.) Ag. is the only species commonly recognized. It varies much and has been separated into a number of species, or at least varieties. The variation in the shape of the bladders, the shape of the blades, of the markings of the blades, and the possession of a prominent "rhizome" or not, etc., is very considerable and future study may compel segregation from the main type.

On our Pacific coasts the "Long bladder kelp," as it is called, extends from the neighborhood of Magdalena Bay, in Lower California (Mexico), to Sitka, in Alaska. All along the coast, in favorable places, it forms belts lying at varying distances of half a mile or more offshore in 20 to 30 meters depth of water. So extensive and so compact are these belts that they form natural breakwaters and are troublesome to steamers passing through them, getting seriously entangled in the propellers. The more extensive beds or "banks" are indicated on the charts of the United States Coast and Geodetic Survey for the information of mariners. For pure bulk, probably easily to be obtained by some proper method of gathering, this kelp excels all others, since it occurs in fairly deep water and is mixed only with the "Bull kelp" or the "Elk kelp," kelps equally desirable, apparently, for harvesting.

### 15. *Pelagophycus* Aresch.

Holdfast of whorls of repeatedly dichotomously branched hapteres; stipe slender and solid below, gradually increasing in diameter and hollow above, constricted just below the summit, and then expanded into a large hollow spherical bladder, from the summit of which the stipe is continued as two stout solid arms; each arm may or may not fork once or even twice symmetrically and then split unequally and unilaterally, giving rise to a few large blades arranged on one side of each arm like a scorpioid cyme, or the branching of each arm may be unilateral from the first; sori in broad patches on the blades.

1. *P. porra* (Leman) Setchell is the only species and is called "Elk kelp," "Sea pumpkin," and "Sea orange." It grows with the preceding along the coasts of California and Mexico (Lower California) from Point Concepcion to Magdalena Bay. It has been found washed ashore, however, as far north as Santa Cruz and the mouth of Tomales Bay. It reaches a length of at least 50 meters and resembles *Nereocystis luetkeana* so much in its hollow stipe and bulb that it has been placed in the same genus by most writers. The unilateral method of splitting, however, necessitates keeping it distinct and placing it nearer *Macrocystis*. Together with *Macrocystis* it inhabits the 12-15 fathom (24-30 meters) zone along the coasts it inhabits.

### Subfamily 3.—LESSONIOPSOIDEAE.

The members of this family present a complexity arising in two ways, viz, by longitudinal splitting at the transition place and also by outgrowths at the transition place. In other words, the members of this subfamily, in the methods of increase in complexity, combine characteristics belonging to the preceding subfamily, the *Lessonioidae*, and the following subfamily, the *Alarioideae*. The vegetative increase is that of the former, the increase connected with reproduction that of the latter. There is but a single species as yet known in this subfamily.



Tribe 6.—*LESSONIOPSEAE*.

Has the characteristics of the subfamily.

16. *Lessoniopsis* Reinke.

Holdfast of stout, branching hapteres; stipe forming a stout trunk which dissolves above into the slender pinnately or dichotomously branched branches, produced in two ways: (1) By continued splitting through which the greater multiplication of branches and the narrow, strap-shaped blades is brought about, and (2) by outgrowths of special broader falcate blades which are produced for bearing the sori; sori on special blades which they cover more or less completely on both surfaces.

1. *L. litoralis* (Farlow and Setchell) Reinke. The only species is a shore kelp, growing on exposed rocks along the Pacific coast of North America from somewhere south of Monterey, Cal., to the southern portion of Vancouver Island, British Columbia.

Subfamily 4.—*ALARIOIDEAE*.

The members of this family are distinguished by the fact that the complexity of the frond arises by outgrowths at the transition place. These may arise on the margins of the transition place nearest the stipe, on those nearest the blade, or on those nearest both. In accordance the subfamily is divided into three tribes, respectively, viz, *Alarieae*, *Ecklonieae*, and *Egregieae*.

Tribe 7.—*ALARIEAE*.

Holdfast of branched hapteres; stipe simple, elongating, with a row of sporophylls on each upper margin, which have successively originated as outgrowths from the transition place on the side toward the stipe.

The members of this tribe are all to be found in the north Atlantic and the north Pacific Oceans, inhabiting the shores of Europe and Asia, and both coasts of North America.

17. *Pterygophora* Rupr.

Holdfast of stout, branched hapteres; stipe solid, elongating, provided with mucilage ducts; blade terminal, elongated, thickened in the meridional region, but without a midrib in strict sense; sporophylls lateral, on both sides of the stipe, elongated, of indefinite growth; sori broad, covering both sides of the sporophylls from the base to a point well above the middle, as well as similarly placed on the terminal blade.

1. *Pt. californica* Rupr. The only species of the genus; on the Pacific coast of North America, ranging from Lower California to the southern end of Vancouver Island; attached to stones and rocks in the lower littoral and sublittoral zones; a robust species.

18. *Alaria* Grev.

Holdfast of stouter or more slender branched hapteres; stipe solid, single more or less stout, with or without mucilage ducts; blade terminal elongated, thin, with a central percurrent, distinct, longitudinal midrib; sporophylls, lateral on both sides of the stipe, longer or shorter, broader or narrower, of definite growth; sori more or less nearly covering both surfaces of the older sporophylls, at least.

*Alaria* is a genus, represented in both the north Atlantic and the north Pacific, and whose species have not as yet been very satisfactorily defined. I have attempted to arrange them intelligibly in the following synopsis, using the distinctions afforded by the relative proportions of the *older* sporophylls. The younger sporophylls, bases of the blades, and cross section of the midrib, are often quite different from the older. The arrangement is as follows:

## A.—MIDRIB SOLID.

## I.—SPOROPHYLLS SHORT AND NARROW.

## 1.—Blade long and narrow.

1. *A. esculenta* (L.) Grev.—Midrib narrow, rectangular in cross section.
2. *A. taeniata* Kjellm.—Midrib narrow, oblong in cross section.

## 2.—Blade long but fairly broad.

3. *A. praelonga* Kjellm.

## II.—SPOROPHYLLS SHORT AND BROAD.

## 1.—Base of adult blade broadly cuneate.

4. *A. tenuifolia* Setchell.—Stipe long, very much flattened, midrib narrow.
5. *A. marginata* P. & R.—Stipe short, nearly cylindrical, midrib broad.
6. *A. pylaii* J. Ag.—Stipe short, nearly cylindrical, midrib narrow.

## 2.—Base of adult blade truncate to subcordate.

7. *A. membranacea* J. Ag.—Stipe long, slender, almost cylindrical.

## III.—SPOROPHYLLS LONG AND NARROW.

## 1.—Midrib narrow, elliptical in cross section.

8. *A. dolichorhachis* Kjellm.—Blade long, attenuate at the base.
9. *A. oblonga* Kjellm.—Blade abruptly and broadly cuneate at the base.

## 2.—Midrib narrow or moderately broad, oblong in cross section.

10. *A. lanceolata* Kjellm.—Blade long, attenuate at the base.
11. *A. musaeifolia* (de la Pyl.) J. Ag.—Blade broadly cuneate at the base.

## 3.—Midrib very broad.

12. *A. laticosta* Kjellm.—Blade long, attenuate at the base.

## IV.—SPOROPHYLLS LONG AND BROAD.

## 1.—Blade long, attenuate at the base.

13. *A. valida* Kjellm. and Setchell.—Midrib broad, prominent.

2.—*Blade truncate to subcordate at the base.*

- 14.
- A. grandifolia*
- J. Ag.—Midrib narrow, little prominent.

## B.—MIDRIB INTERRUPTEDLY HOLLOW.

- 15.
- A. fistulosa*
- P. & R.

## A.—MIDRIB SOLID.

I.—*Sporophylls short and narrow.*

1. *A. esculenta* (L.) Grev. has a narrow midrib, prominent, rectangular in cross section and a long narrow blade, long attenuate at the base. It is common on the Atlantic coast of the United States from Cape Cod northward.
2. *A. taeniata* Kjellm. is very similar to *A. esculenta*, but has a less prominent midrib, oblong in cross section, as have also *A. angusta* Kjellm. and *A. crispa* Kjellm., here temporarily placed under it. All three species, founded on younger specimens, are found in Bering Sea to the northward, and have not been seen since the original collection.
3. *A. praelonga* Kjellm. is a somewhat larger species than the last, but agreeing in all essential characteristics. The species was founded on older and more mature specimens than the three I have just included under *A. taeniata*. Kjellmann says that it was fairly abundant on Bering Island and he also has included specimens collected on St. Paul of the Pribilof Islands and on Kadiak Island, Alaska.

II.—*Sporophylls short and broad.*

4. *A. tenuifolia* Setchell is to be distinguished by its long, flattened stipe, only moderately broad midrib, short and relatively broad sporophylls, and blade broadly cuneate at the base. It is a Pacific coast species and extends from Juneau, Alaska, on and up into Bering Sea.
5. *A. marginata* P. & R. is a species of the Pacific coast to be distinguished from the last by its nearly cylindrical short stipe, short and fairly broad sporophylls, and broad midrib. It occurs on the coasts of middle and northern California and of Oregon.
6. *A. pylaii* J. Ag. is a species of both coasts of North America, although on the eastern coast it probably does not occur within the limits of the United States. On the Pacific coast it is known from the vicinity of Prince William Sound and Kadiak Island. It is to be distinguished from others of this group by its short stipe, narrow midrib, and broadly cuneate base of the blade. The sporophylls are short and only moderately broad.
7. *A. membranacea* J. Ag. is a species which may occur on either coast. At present it is known from North America only from Baffin Bay, but it may range farther south. It is described as having a long, slender stipe, a rather narrow midrib, and with the base of the blade truncate to subcordate. The first sporophylls are ample, being almost broader than long, but the later ones are about 4 to 6 times as long as broad.

III.—*Sporophylls long and narrow.*

8. *A. dolichorhachis* Kjellm. has the midrib only moderately broad, little prominent on either surface, and elliptical in cross section, the base of the blade long attenuate, and the sporophylls very long and narrow. It has been found only on Agattu, one of the Aleutian Islands, within our territory. It is said also to occur in the Siberian Sea and possibly also in the American Arctic Sea.
9. *A. oblonga* Kjellm. is reported only from the Siberian Sea, but may, perhaps, be looked for in the Bering Sea. It has a narrow prominent midrib, oblong in cross section, the base of the blade suddenly and broadly cuneate, and the sporophylls moderately long and narrow.
10. *A. lanceolata* Kjellm. resembles *A. dolichorhachis*, but has a more prominent midrib, oblong in cross section of the adult. The type locality is Bering Island, in Bering Sea, and it occurs also on Amaknak Island in the Bay of Unalaska, at Glacier Bay, and at Sitka, Alaska.

11. *A. musaeifolia* (de la Pyl.) J. Ag. has a varying but fairly broad, prominent midrib, oblong in cross section, a broadly cuneate base to the blade, and long, narrow, at times (especially when young) falcate sporophylls. It occurs on the Atlantic coast from Maine to Newfoundland, at least.
12. *A. laticosta* Kjellm. is to be distinguished by its very broad (up to 1.5 centimeters wide) midrib. The base is long and gradually attenuate and the sporophylls are moderately long and fairly narrow. It is described from specimens collected at Bering Island in Bering Sea, and plants from Kukak Bay, Alaska, have been referred here with some doubt.

## D.—SPOROPHYLLS LONG AND BROAD.

13. *A. valida* S. & G. has a longer or shorter, stout stipe, a broad, prominent midrib, a blade with broad but gradually attenuate base, and very long, moderately broad sporophylls. It ranges along the Pacific coast from Whidby Island, Wash., to Unga Island, Alaska.
14. *A. grandifolia* J. Ag. resembles the last, but the blade is truncate or subcordate; the costa narrower and little prominent. It bears about the same relation to *A. valida* that *A. membranacea* does to *A. pylati*, except that the difference in shape of the base of the blade is more striking in this case. It is not known from our territory, but may be expected on either coast and to the north.

## B.—MIDRIB INTERRUPTEDLY HOLLOW.

15. *A. fistulosa* P. & R. is a variable, possibly composite species very abundant along the Pacific coast from Wrangell Narrows, Alaska, north into Bering Sea and over into the Kurile Islands and Ochotsk Sea on the coast of Asia. It is a large species, reaching a length of 25 meters, with broader or narrow blade, but to be distinguished by its broad, interruptedly fistulous midrib. It is met with floating, often in great quantity, throughout its territory. It usually grows in deep water (20 to 30 meters) and sends its blade up to float along the surface, buoyed up by the fistulous midrib.

## Tribe 9.—ECKLONIEAE.

The members of this tribe show their relationship to the Alarieae by having the complexity of the frond arise by outgrowths at the transit place. The Ecklonieae, however, differ from the Alarieae by having the outgrowths situated on the margins of the transition place nearest the blade, so that the developing structures form projections from the margins of the blade. This gives rise to a pinnate blade which may or may not be further modified. The tribe contains four genera—Ecklonia, Eisenia, Undaria, and Hirome—of which only one, viz, Ecklonia, is found on our Pacific coast. Undaria and Hirome are restricted to Japan, which also has species of both the other genera. Species of Ecklonia also occur in the Southern Hemisphere on the coast of Cape Colony in Africa, in Australia, in New Zealand, and also on the coasts of South America.

19. *Eisenia* Aresch.

Holdfast of branching hapteres; stipe persistent, elongating, passing above into two stout arms formed by the thickened bases of the blade which wears away in the meridional region; blade at first simple, becoming deeply pinnate by the outgrowths arising at the base, wearing away in the center, leaving the thickened bases as arms (apparently as branches) of the stipe, each arm supporting a small basal blade bearing a number of sporophylls; sori in extended areas of irregular shape on the sporophylls.

In the behavior of the meridional region of the blade in wearing away to the transition place, leaving the bases to thicken and to grow into arms which bear partial (in this case very small) blades with the sporophylls, there is a certain resemblance to the course of development in *Hedophyllum* (*H. subsessile* and *H. spirale*) and *Thalassiophyllum*, as well as a suggestion of the *Lessonioidae* and even more particularly the *Lessoniopsoideae*. With the latter, except for detail, the resemblance is striking. Nevertheless, the relationships seem with the *Ecklonieae* rather than with any other group of the *Laminariaceae*.

1. *E. arborea* Aresch. is our only species which is found on the coast of southern California. It differs from *E. bicyclis* (Kjellm.) Setchell of the Japanese coast by having the sporophylls always simple. It is sometimes called "Sea Tree" and "Sea Oak."

#### Tribe 10.—EGREGIEAE.

There is only one genus in this tribe, and it resembles in its peculiarities the other two tribes of the *Alarioideae*. Its increase in complexity is by outgrowths from the transition place, but they originate on both the stipe side and the blade side of the transition place, so that in developing, the members of this tribe combine the peculiarities of the *Alarieae* and the *Ecklonieae*, possessing sporophylls (or, at least, pinnae) on both stipe and blade and forming a most complex frond. The two species belonging to the single genus of this tribe are found only on the Pacific coast of North America.

#### 19. *Egregia* Aresch.

Holdfast of branching hapteres; stipe persistent, elongating, and branched, flattened, bearing outgrowths on both margins throughout its length, some of the latter being provided with elongated bladders; blades comparatively small, more or less pinnate with outgrowths; sori on small sporophylls more or less covering both surfaces.

*Egregia* has two species, which may be distinguished by the characters of the stipe (rhachis). In one, *E. menziesii*, the stipe is closely covered with short blunt papillae, and in the other, *E. laevigata*, it is smooth.

1. *E. menziesii* (Turn.) Aresch. is a plant reaching a length of nearly 10 meters, much branched, with the flattened stipe (or rhachis) roughened on both sides with short blunt papillae and with its margins closely beset with short, simple, smooth, obovate leaflets, some of which bear ellipsoidal bladders at the base and some of which bear sori. It extends from Point Concepcion, on the California coast, to the southern end of Vancouver Island, British Columbia.
2. *E. laevigata* Setchell is a much branched plant, similar in general structure to the last, but its flattened stipe is smooth, as are also the small, deeply pinnate blades; the leaflets are, in older plants, smooth and pinnate, often almost capillary; also at times bearing elongated bladders or sori. It is often called the "Feather boa kelp." It is restricted to the coast of California south of Point Concepcion, and extends down a way along the western coast of Mexico.

## ECONOMIC CONSIDERATIONS.

The seaweeds, on account of their abundance and different properties, were used in one way or another by primitive peoples inhabiting seashores or adjacent inland districts, and with the spread of civilization their use has been continued and extended. With the Japanese, Chinese, and Hawaiians they form an article of commerce of considerable importance.

Of the seaweeds, the members of the kelp family or Laminariaceae have been the most used by man. This is probably due more to their larger size and greater abundance rather than to any chemical or physical differences. In their natural state some have been used as food for man; some as food for domestic animals, particularly cattle; and some in medicine; while subjected to various processes they have yielded a number of valuable substances, among which are soda, potash, iodine, and algin. All these uses have been known for a long period, running perhaps into a number of centuries. The use of kelps has been largely discontinued by the greater number of civilized nations owing to the discovery of other more available sources of supply of the products mentioned. The Chinese and Japanese still use large quantities of seaweeds as food, either in their natural state or as manufactured products.

## HUMAN FOOD.

The seaweed foods do not form the staple article of diet of any nation, but are used as relishes or accessories. The most prominent of these among the Caucasian races is *Alaria esculenta*. Greville (1830, p. 26) says: "The midribs of this plant, when stripped of the membrane, and sometimes also the leaflets, are eaten in Ireland, Scotland, Iceland, Denmark, and the Faroe Islands. It is called in Scotland *Badderlocks* or *Hen-ware* and in the Orkney Islands *Honey-ware*. Dr. Drummond informs me that in some parts of Ireland it bears the name of *Murlins*." Turner (1809, p. 121) spoke of it somewhat earlier as follows: "The plant is much eaten in Scotland; the parts employed for that purpose are the midrib, stripped of its membrane, which is extremely sweet, and the thick part of the pinnae, which are called *Keys*. The latter, however, are only brought to market when thick and fleshy, never when thin and membranous. It goes by the name of *Daberlocks*. According to Lightfoot its proper season is September; and he also observes that it is recommended in the disorder called a *pica*, to strengthen the stomach and restore an appetite."

*Laminaria digitata* also has been used as food. Turner (1809, p. 68) says on the authority of Bishop Gunner that "the stem is sometimes, when boiled, eaten by men." Foslie (1884, pp. 38, 39) translates Stephensen as saying that the Icelanders used the upper part of the stipe and the undivided portion of the blade of *L. hyperborea*, preparing a mush which was resorted to only in times of need. Greville (1830, p. 29), in speaking of this species, says: "In Scotland, where the tender stocks of the young fronds are eaten and still cried about the streets of Edinburgh, it is called *Tangle*." The Indians in California and perhaps also in other regions of the Pacific coast, especially those living near but not in direct contact

with the coast, go down to the shore and collect the coarser red and brown seaweeds, dry them, and carry them home for use as food. Probably the salt content is one of the things desired. Among such brown seaweeds, the bulbs and upper parts of the hollow stipe of *Nereocystis luetkeana* are much sought for.

These uses, however, are (or were) local and of small amount; the Japanese, however, have a regular trade in procuring, drying, and packing various Laminariaceae for home consumption and for export to China and other countries where Japanese and Chinese are settled, while the inhabitants of the shore in Japan make use also of the fresh plants. Various articles have been published concerning this industry of Japan, but the one by Yendo in *Postelsia* for 1901 (the Yearbook of the Minnesota Seaside Station), is the most explicit in English. The report by Miyabe, Yanagawa, and Ushina, published as a part of the report of the Hokkaido Fisheries Bureau, is extended and thorough, but is inaccessible to all except Japanese, since it is printed in that language. Some of it has been utilized in the account by Hugh M. Smith in "The Seaweed Industries of Japan," published in *Bulletin of the Bureau of Fisheries of the United States Department of Commerce and Labor* (Vol. XXIV, pp. 135-165).

The chief supply is from the several species of *Laminaria* which are called "*Kombu*." There is a considerable number of boats and men, among them Ainu as well as Japanese, engaged in the gathering. In the proper season, July to October, the kombu fishers go to the kelp beds in open boats and with various implements drag, twist, or cut the kelps from their attachment to the rocks in water of a few fathoms deep, load it aboard, and take it to the shore. Here it is spread out carefully on the beaches near the villages to dry and cure in the open air. When thoroughly dried the kombu is taken under cover and prepared for shipment to the manufacturers. Only the better portions of the blade are retained; the stipe and older portions of the blade are rejected. The part selected is neatly shaped, and the different kinds, grades, and sizes of kombu are assorted and tied up in long, flat bundles.

From the kombu thus roughly cured and packed more than a dozen commodities are manufactured. From the same raw material are made varied products which appeal to one or another taste. Most of the preparations of kombu do not appeal to the American palate, but some, if introduced under favorable circumstances, might become an article of diet in this country.

The most important preparation is the shredded or sliced kombu. This is dyed to give it a uniform green color, but this in no wise changes its flavor or food value. Formerly this coloring was done with copper, but this is now forbidden by law. In the manufacture the raw kelp is placed in a strong solution of an aniline dye (malachite green) in fresh water and boiled for 15 to 20 minutes, being stirred vigorously from time to time; after this thorough cooking and coloring the mass is drained and taken into the open air for drying. When the surface is dry the fronds are separated and laid flat in wooden frames and cut into equal lengths. These are then placed in other frames, sprinkled with water to make them pack tight, and compressed into a solid mass. One side of the frame being removed for the purpose, the fronds are cut lengthwise with a plane into long

thin shreds. The shredded mass resulting is finally spread on mats in the open air and frequently turned to secure uniformity in drying. When the outer portion is dry, but enough moisture remains to keep the shreds pliable, they are stored under cover to await packing and shipment. They are packed in paper for use at home and into wooden boxes for export to China and other countries.

The kombu described above is made of the thinner fronds, but the thicker fronds are sorted out and subjected to a series of processes, each of which results in a particular product. First, they are thoroughly soaked in vinegar, drained, and dried in the open air. The first preparation consists in scraping away the epidermal layers with a rough-edged knife. The first scrapings naturally contain some grit and are the cheapest kombu. Then deeper scraping until the outer greenish tissues are removed gives a product called the *Kurotororo kombu* or black pulpy kombu. The white core remaining after the green has been scraped, if scraped again with the same sort of knife, gives a fine, white, stringy mass, which is known as *Shirotororo kombu* or white pulpy kombu; or a sharp-edged knife may be used to separate delicate and filmy sheets of various sizes, and this is called *Oboro kombu* or filmy kombu. The thin central bands left after either of these two last-mentioned processes are pressed together, cut into equal lengths, and cut into shreds with a plane after the fashion of the green-dyed kombu. The shavings look like coarse white hair and are called *Shirago kombu* or white-hair kombu.

Other preparations may be made from what remains after the first scraping. It may be cut into strips, oblongs, squares, triangles, etc., and dried over a fire, making *Hoiro kombu* or dried-on-the-fire kombu, or the strips may be coated with white or pink icing and sold under the name of *Kwashi kombu* or sweet cake kombu. The *Hoiro* or dried-on-the-fire kombu may be pulverized and put through a fine wire sieve, giving a grayish powder known as *Saimatsu kombu* or finely powdered kombu, and this is often compressed into small cakes of various shapes and powdered with sugar. There is another product made in the same way as the white-hair or *Shirago kombu*, the shreds, after drying, being cut into lengths of about half an inch. This is called *Cha kombu*, or tea kombu, from its resemblance and the method of cooking it.

The Japanese all use the kombu preparations in one or more of its forms. It is eaten without cooking or after treatment with hot water or in the form of the crisp sugared strips. The filmy kombu and the powdered kombu are used to impart flavor to soups, sauces, etc., and the powdered is used as curry powder is. Strips of the dried and untreated kombu are cooked with meat or vegetables, as are also the shreds of green kombu. Broad strips of untreated kombu are boiled in fresh water for awhile and then, being cut into suitable lengths, are wrapped about dried herring, cod, or other fish, and cooked in dilute soy, soup, or milk. This dish is called *Kombu mati* or *Kombu roll*.

Of the value of the trade in kombu, fairly accurate figures are available. In 1901 the Kokkaido fishermen received \$464,000 for their crop and the manufacturers about 60 per cent additional, although the exact amount of the latter's receipts is not obtainable. It is a business which is increasing, and it is being fostered by the Japanese Government.



While kombu is largely prepared from species of *Laminaria*, particularly from the long, broad, and thick *L. japonica* and the short, narrow, and stiff *L. angustata*, other species, such as *Arthrothamnus bifidus* and *A. kurilensis*, and some species of *Alaria* are also used. Yendo (1902, p. 6) says that *Undaria pinnatifida* is also dried and used under the name of *Wakame*, and that the peasantry of north Japan cut off the sporophylls of this species and, pressing them into a slimy liquid with peculiar and distinctive odor, mix it with boiled rice. *Eisenia bicyclis*, he also says, is used under the name of *Arane* and in the same way as *Undaria*.

A series of chemical analyses of some of the species of *Laminaria* and *Arthrothamnus* used commercially was made by Oshima and published in the Japanese treatise alluded to above. A translation is to be found in the article by Hugh M. Smith (1905, p. 153) on the "Seaweed industries of Japan," already cited.

No attempt has been made in this country to utilize any of the abundant material of the Laminariaceae for food purposes. In Seattle a product known as "seatron" has been made from the bulbs of *Nereocystis luetkeana*.

#### FODDER FOR DOMESTIC ANIMALS.

The Laminariaceae have long been used in connection with the feeding of cattle, especially in Norway. Turner (1809, p. 68) states in connection with *Fucus digitatus* (*Laminaria hyperborea* and *L. digitata*) that "Bishop Gunner, who has given an excellent account of it, says that in Nordland the stems and fronds of young specimens are boiled and given to cattle." This was probably rather *Laminaria hyperborea* than *L. digitata*. Foslie (1884, p. 38) repeats the statement and vouches for its accuracy. He says also that both *L. hyperborea* and *L. digitata* are used in winter as a substitute for hay for cattle in Finnmarken. Later in the same work Foslie (loc. cit., pp. 54, 55) says that in East Finnmarken the inhabitants use *Alaria* and *Laminaria* as fodder for cattle, of the species of *Laminaria*, *L. digitata* mostly, but partly also *L. hyperborea*. One species of *Laminaria*, however, was suspected of poisoning and even of causing the death of cattle when mixed with the ordinary species. So far as Foslie could determine, the suspected plant was likely to prove to be his *L. gunneri*.

In the summer of 1899 I was told by several people that kelp was used as food for cattle on the coast of Alaska, particularly on Kadiak Island, but I was not able to obtain any details as to the extent or manner of feeding.

#### MANURING.

For a very long period of time farmers sufficiently near a shore furnishing an abundance of Laminariaceous (or even other seaweed) material have been in the habit of carting it onto the land and spreading it out as a top dressing to decompose in position, or have previously composted it. This has been done all along the outer western coasts of Europe and on the coast of New England in the United States. There has been universally favorable testimony to its efficacy, particularly for the production of heavier crops of turnips, wheat, potatoes, etc. It has also been used in Japan for the same purpose. Turner (1809, p. 68) says of *Fucus digitatus* (*Laminaria hyperborea* and *L. digitata*): "This *Fucus* is commonly used in the manufacture

of kelp, and is no inconsiderable article of manure on the coasts where it abounds," and quotes Bishop Gunner to the effect that, in a putrid state, they are used in Lofoten and Vesteraalen to manure the fields. Foslie (1884, p. 53) states that in the preceding year (1883) a farmer in Jaederen, a district of southwestern Norway, had used 2,000 cart-loads of *Laminaria* for manuring. This was mostly *L. hyperborea* and was only a small portion of what was thrown up in the winter on the shores of the farmer's own property. Greville (1830, p. 29), speaking of *Laminaria digitata*, says: "On many parts of the British coast it is collected and thrown in heaps and in a putrescent state extensively used as manure. De la Pylaie (1825, p. 180) states that *Saccorhiza bulbosa* furnishes the best manure and that thistles grow so luxuriantly and abundantly on fields over which it has been spread that the peasants have a belief that it engenders them. Various algae, but particularly the rockweeds (Fucaceae) and kelps (Laminariaceae), under the name of *Varech* or *Goëmon* are used either fresh, dried, or burned on the coasts of Brittany and Normandy in France. The *Varech* is either cast up on the shore and collected and carted off or it is raked from the rocks which are uncovered by the tides or only slightly covered with water. If accessible, the *Varech* is loaded onto carts, but if not, it is collected and placed on lighters. The plants always have a number of small shells attached to them, which greatly increase their fertilizing value, but they are otherwise rich in alkaline salts which gives them fertilizing value. The account by Isid. Pierre in Moll and Gayot's *Encyclopedic pratique de l'agriculteur* (1882) gives considerable material concerning the nature, use, and value of *Varech* (or *Goëmon*) as a manure. His account has been followed by me. If this source of fertilizer should be suddenly withdrawn from the farmers of Brittany and Normandy there would be a distinct lessening of the luxuriance of the vegetation for which these coasts are famous. The "*Goëmon vert*," says Pierre in 1882, either cast ashore or cut, is the only fertilizer used in a band of territory of 400 kilometers, extending from Paimpol to Brest and extending inland 500 meters from the sea. About 30 to 40 cubic meters of this manure is needed for each hectare. He quotes M. de Kerjégu as saying that it is such lands which produce continuously 40 hectoliters of wheat and 60 hectoliters of barley and rent for 150 to 200 francs a hectare. Also he adds that the "*Goëmon vert*" forms two-thirds of the manure for a distance comprised between 2 and 8 kilometers from the source of supply. The price of this precious substance more than doubled between 1863 and the time of writing (1881 or 1882). A cubic meter of "*Goëmon*" is estimated fresh to be between 400 and 450 kilograms and the dried "*Goëmon*" at 250 to 300 kilograms. The latter sells at three times the price of the former.

In each community there are ordinarily police regulations for each locality as to the time and mode of collection. The seaweed cast ashore may be gathered at all favorable times. National laws also regulating ownership and traffic in *Varech* have existed for two or three centuries, at least in France, and there has been a conflict of interests between those using it for fertilizer and those wishing to use the soda and potash from the ashes of the burnt *Varech*, as will be alluded to later.

The fresh seaweed is simply drained and either heaped together, when putrefaction soon sets in, or it is burned after having been

dried. There seems to be no agreement as to the best way of using the seaweed as fertilizer, but there is a general belief that it is harmful unless it has been exposed for some days to the action of the atmosphere and has also been deprived of its excess of salt by some showers, or at least proper drainage. Sometimes it is washed and dried, used as fuel, and then the ashes resulting are used as fertilizer. These and other references indicate that there is and has been an extensive use of *Varech*, particularly of the digitate *Laminariae* and *Laminaria saccharina* on the northwest coast of France for manuring.

Of the other coasts of western Europe more has been written about the use of kelp as fertilizer in Scotland than in any other country. The origin, rise, and fall of the "manufacture of kelp," much discussed, has reference chiefly to the manufacture of kelp ash by burning rather than to manuring in the proper sense, and this kelp ash was used by the soap boiler and the glassmaker, as well as for fertilizer. This matter will be taken up under the "Manufacture of kelp" below.

Greville (1830, p. XXIV) has the following to say about the use of seaweed in manuring: "It has long been known that common sea ware is extremely valuable for that purpose; and if the success which has attended the experiments already made with kelp be confirmed by additional observations, the manufacture may still be regarded as an important article of domestic commerce. It appears from the communications made to the Highland Society that the past success has been such as to induce Lord Dundas to take a cargo of 50 tons of kelp to Yorkshire for the sole purpose of agricultural experiments. It has been tried as a top dressing, and singly or in combination with other manures on corn, pasture, potatoes, turnips, etc., and in most instances with decided good effect. The committee appointed to collect the result of the experiments are inclined to think that for raising green crops it would be better to compost it with other substances; that with good earth or moss and a little vegetable or animal manure, 'a few tons of kelp would enable a farmer to extend his farm dung over at least four times the usual quantity of land.' A very curious circumstance is mentioned by Charles Mackintosh, Esq., who tried the effects of kelp manure upon potatoes at Crossbasket, near Glasgow. A severe frost, which occurred in September, injured and blackened every lot of potatoes to which the kelp had not been applied, while the kelp lots remained in perfect foliage, even when the respective drills were contiguous. It would appear that the soil for the time being had acquired a property equivalent to a certain degree of atmospheric temperature; or, rather, that the nourishment absorbed by the plants under such circumstances had enabled them to resist a degree of cold that would otherwise have destroyed them."

The *Algae* grow very rapidly, and the produce is far less exposed to casualties than the crops of the agriculturist in so precarious a climate as that of the Hebrides and Orkney Islands. I am informed that in some places the seaweed is cut only every third year, while in others, especially where there are strong currents, an annual harvest may be obtained without injury. The rapidity of development in the larger *Algae* is indeed so striking that I can not resist the temptation of transcribing some very interesting facts related by Mr. Neill: "They were observed in the course of the very arduous undertaking of erecting a stone beacon on a low rock called the Carr, situated near the en-

trance of the Frith of Forth; and when we mention as the observer the distinguished civil engineer, Mr. Stevenson, a man accustomed to habits of accurate observation, it is perhaps superfluous to add that particular attention was bestowed at the request of the writer of this article, and specimens of the *Algae* transmitted to him. The Carr Rock is about 20 feet broad and 60 feet long; it is only uncovered at the lowest ebb of spring tides. It was completely clothed with the larger *Algae*, particularly *Fucus esculentus* and *F. digitatus*. In the course of the autumn 1813 the workmen had succeeded in clearing out and leveling with the pick and ax a considerable part of the foundation of the intended beacon, when in the beginning of November the operations were necessarily abandoned for the winter. At this time the rock was reduced to a bare state. The coating of seaweed had at first been cut away by the workmen; the roots or bases were afterwards trampled by their feet, and much of the surface of the rock had been chiseled. Upon returning to the Carr in May, 1814, in order to recommence operations, it was matter of no slight surprise to find the surface again as completely invested with large seaweeds as ever it was, although little more than six months had elapsed since the work had been left off, when, as already said, the rock had been cleared of weed. In particular, it was observed that many newly produced specimens of *Fucus esculentus* measured 6 feet in length, and were already furnished with the small appendages near the base or *pinnae*, which at maturity contain the seeds of the plant. The common tangle, *F. digitatus*, was generally only about 2 feet long. It is to be observed that the specimens here alluded to were taken from that part of the surface of the rock which had been dressed off with the pick and chisel the preceding autumn; they had therefore grown from the seed.

Attention may also be called to a paper by James Hendrick (1898), entitled, "The Use and Value of Seaweed as Manure," which gives details of the seaweeds used, chemical analyses of the same, and plot experiments carried on. The plants are divided into "*cutweed*" or "*shoreweed*," made up of the various rockweeds or members of the Fucaceae, and "*driftweed*" or "*tangle*," made up of members of the Laminariaceae, particularly of *Laminaria digitata* and *L. saccharina*. He states that driftweed is more largely used in the southwest of Scotland, where cutweed is held in less esteem, while in the north of Scotland cutweed is the more highly valued. However, ideas varied in various districts of the north. Mr. Hendrick finds reasons for this, viz, that seaweeds are mainly a potassic manure and that the difference in soils as to content of potash causes a difference in the manner of response to the application of seaweeds; and further that on the better soils it happens that they have available farm manures rich in potash. A series of chemical analyses of both sorts, in both wet and dry state, follows (cf. pp. 123, 125, and 126), showing the content of potash to be greater in the Laminariaceous constituent of the driftweed. A comparison between the seaweed manure and barnyard manure follows. Chemically the farmyard manure, though variable, is a more balanced manure and may be used more generally. Seaweed, on the other hand, contains about the same proportion of nitrogen as rotted dung, but much less phosphate and much more potash. Seaweed, in consequence, requires to be used with much more discrimination in order to get the best results with it. It must always be borne in mind that it is specially deficient in phosphoric acid and specially rich in potash. This matter is still further emphasized when we inquire into the state in which variable constituents exist in seaweed, and whether they are readily available to plants.

The nitrogen of seaweed is all present as organic nitrogen, chiefly in albuminoids. It is therefore not available to plants until it has undergone decomposition and nitrification. Thus seaweed has to decay before its nitrogen is

of any use to crops. It is therefore either rotted by allowing it to lie mixed with dung for some time or is applied to the soil some months before the crop will require it, and plowed down. Under these conditions it decays very rapidly and some of its nitrogen soon becomes available. If, then, seaweed be allowed to rot for some time, either in the soil or in a manure heap, its nitrogen becomes comparable in value to that of dung. In rotted dung a certain proportion of the nitrogen is present as ammonium salts, and is almost immediately available to plants, while the greater proportion only slowly becomes available through further decomposition in the soil. A considerable proportion of the nitrogen of dung—that of the straw, for example—becomes available only very slowly. Seaweed, to begin with, has no nitrogen in an available state, but as it rots very rapidly its nitrogen becomes available steadily and gradually, and is therefore of fair value as a fertilizing substance. This is a point, however, which will receive its best illustration from field experiment.

Similar remarks to those made on the nitrogen apply to the small quantity of phosphate contained in seaweed.

The case of potash is different. If we burn seaweed and examine the ash we find that a very large proportion of it is soluble in water. Not only do seaweeds differ from most land plants in containing a great deal more ash, but their ash is of a very different composition from that of ordinary land plants, and a much larger proportion of it is soluble in water. In that part of the ash which is soluble in water all the potash is found, chiefly in the forms of potassium chloride and potassium sulphate, substances known among manures as muriate and sulphate of potash. But not only is all the potash soluble in water after the seaweed is decomposed by burning, but if we take the perfectly fresh seaweed and place it in fresh water, it will be found that a considerable proportion of its potash will be dissolved out chiefly as potassium chloride. We may safely assume, then, that part of the potash of seaweed used as manure is immediately available to plants, and the rest will readily become so as the seaweed undergoes the slow combustion of decay. This further emphasizes the fact that seaweed is especially a potassic manure, for while its nitrogen and phosphoric acid only become available by decay, part at least of its potash is immediately available.

To sum up: While seaweed is not strictly comparable with farmyard manure, it has about the same value per ton. It is an all-around manure specially rich in potash and specially poor in phosphate. While, just as in the case of farmyard manure, it is difficult to place an exact money value per ton on it, it has a considerable value for all-round manuring if supplemented with some phosphatic manure, and in special cases by some sulphate of ammonia or nitrate of soda; and it has a special value for all soils deficient in potash and for all crops which specially require potash. Its richness in potash partly explains why it is so largely used for potatoes, and why, when used on pasture, it is said to cause such a marvelous growth of clover. Certainly if it pays to carry town manure long distances by rail and road, as is constantly done, it should pay to go to some little expense and trouble to save large quantities of wrack, both cutweed and driftweed, which are allowed to go to waste round some parts of our coasts.

A subsidiary, but by no means unimportant, advantage which seaweed has over dung is that it does not carry the germs of diseases nor the seeds of weeds. We can not sow out finger and toe, for instance, on the land by means of seaweed as is too often done by means of dung.

As to the plot experiments carried out under the direction of Mr. Berwick, he summarized as follows:

If now we look at the results of all four experiments it will be seen that, weight for weight of manure, seaweed gives just as great a crop of potatoes as farmyard manure. When superphosphate is applied along with the seaweed, the crop is in every case increased, and except in the case of Rosenearth, where analysis shows the soil itself to have been high in "available" phosphate, the increases are very considerable. On the other hand, in no case does the addition of superphosphate to the farmyard manure give any corresponding increase of crop. The crops with dung alone and with dung and superphosphate are practically the same. Seaweed with superphosphate gave a larger crop in every case than farmyard manure with superphosphate or farmyard manure alone. Even when potash also was added to the dung there was no improvement, but the contrary. Seaweed, then, when supplemented with superphos-

phate, seems capable of giving somewhat larger crops of potatoes than dung. The addition of superphosphate both with dung and seaweed had the effect of making the produce somewhat more mature.

On the other hand, dung had the advantage over seaweed in quality of produce. In all cases quality as well as quantity was looked to. While quality can not be accurately measured like quantity, there was no doubt that the seaweed potatoes were less mature than the dung ones. They were softer and less mealy when boiled, and in every case it was held that the results of the seaweed plots would have been improved if they could have been allowed to grow for a fortnight longer. It is therefore probable that seaweed would give even better results with late potatoes.

As no nitrogenous manure was applied with the seaweed in any of the experiments, and at Turnberry the soil was very deficient in nitrogen, the results would seem to indicate that the nitrogen of seaweed readily becomes available to potatoes, and is, on the whole, of equal value to that of dung.

The field experiments, then, confirm the results of analysis, and show that seaweed is, weight for weight, as good a manure for potatoes as dung, but that, to get the best results with it, it should be supplemented with phosphate. The results in Tables V and VII do not show that sulphate of potash has any advantage over muriate, so far as weight of crop is concerned, nor could good judges find any difference in quality or maturity in favor of sulphate. So far as these experiments go, then, there does not seem to be much ground for the general belief that muriate of potash is not a suitable manure for potatoes. Used in moderate quantity it seems to be quite as useful a manure as sulphate of potash.

On our own New England coast the farmers have long made use of driftweed, which is chiefly made up of *Laminaria digitata* and *L. saccharina*. After storms in autumn, winter, and spring the "weed" comes ashore in quantities, forming windrows several feet high along the beaches. It is carted onto the land and used in various ways. The matter has been noticed in several publications, but particularly in Bulletin 21 of the Rhode Island Agricultural Experiment Station (Jan., 1893), where the matter has been gone into most thoroughly by H. J. Wheeler and B. L. Hartwell. The history and literature of the subject is given in extensive detail. They state, quoting the Rhode Island State census for 1885, that the value of the seaweed used as fertilizer within that State for that year was \$65,044, while that of commercial fertilizers was \$164,133, noting that consequently "the seaweed" interest is a large one, even for Rhode Island. In this bulletin the authors go into the matters of chemical analyses, methods and times of using, and manurial values, both absolute and comparative, in thorough fashion.

Storer (1888, 1: pp: 444, 445) speaks of seaweed as a "potassic manure," and hence especially favorable to the growth of clover, and says that it has successively given fine crops of clover for many years on land on which it, and no other manure, has been used.

#### MANUFACTURE OF "KELP."

"Kelp," in a modified sense, is a term applied to the ash left after the combustion of certain members of the Laminariaceae. This ash contains potassium and sodium salts as well as iodine. For the last of these it was for a long time the principal, practically the sole, source, and for the first two also a considerable source, vying with "barilla," the ash of certain salt-marsh plants of the pigweed family (Chenopodiaceae), as a supply of these materials for the soap boiler and the glass manufacturer. The manufacture of "kelp" was particularly carried on along the coasts of Ireland, of northern Scotland, and of the Orkney Islands.

A good account of the rise and progress of this manufacture is given by Greville (1830, pp. XXI-XXIV):

In the manufacture of kelp, however, for the use of the glassmaker and soap boiler, it is that the *Algae* take their place among the most useful vegetables. The species most valued for this purpose are *Fucus vesiculosus*, *nodosus*, and *serratus*, *Laminaria digitata* and *bulbosa*, *Himanthalia lorea* and *Chorda flum.* The manufacture of kelp was introduced into Scotland, according to Mr. Neill, half a century subsequent to its establishment in France and England, and the first cargo exported from Orkney was about the year 1722. The employment, however, being new to the inhabitants of Orkney, the country people opposed it with the utmost vehemence. Their ancestors had never thought of making kelp, and it would appear that they themselves had no wish to render their posterity wiser in this matter. So violent and unanimous was the resistance that officers of justice were found necessary to protect the individuals employed in the work. Several trials were the consequences of these outrages. It was gravely pleaded in a court of law, on the part of the defendants, "that the suffocating smoke that issued from the kelp kilns would sicken or kill every species of fish on the coast or drive them into the ocean far beyond the reach of the fishermen; blast the corn and the grass on their farms; introduce diseases of various kinds; and smite with barrenness their sheep, horses, and cattle, and even their own families." The proceedings exist, as I am informed by Mr. Peterkin, in the records of the sheriff court, a striking instance of the prejudices, indolence, and superstition of the simple people of Orkney in those days. The influential individuals who had taken the matter up succeeded in establishing the manufacture, and the benefits which accrued to the community soon wrought a change in the public feeling. The value of estates possessing a seacoast well stocked with seaweed rose so much in value that where the plants did not grow naturally attempts were made, and not without success, to cultivate them by covering the sandy bays with large stones. By this method a crop of *fuci* has been obtained, as we are informed by Mr. Neill, in about three years, the sea appearing to abound everywhere with the necessary seeds. Upon the authority of Dr. Barry (*History of the Orkney Islands*, p. 383), during the years 1790 to 1800 the quantity sometimes made was 3,000 tons, and as the price was then from £9 to £10 per ton, the manufacturer brought into the place nearly 30,000 pounds sterling sometimes in one season. During the 80 years subsequent to its introduction (from 1720 to 1800) the total value will rise to 595,000 pounds sterling. Thus, says Dr. Barry, "In the space of 80 years the proprietors of these islands, whose land rent does not exceed £8,000 a year, have, together with their tenants and their servants, received, in addition to their incomes, the enormous sum of more than half a million sterling."

Among the Hebrides, also, large quantities of kelp are manufactured. "The inhabitants of Canna," observes Dr. E. D. Clarke (*Life and Remains of E. D. Clarke*, by Otter, Vol. I, p. 338), in 1797, "like those of the neighboring islands, are chiefly occupied in the manufacture of kelp. Cattle and kelp constitute, in fact, the chief objects of commerce in the Hebrides. The first toast usually given on all festive occasions is, *A high price to kelp and cattle*. In this every islander is interested, and it always is drunk with evident symptoms of sincerity. The discovery of manufacturing kelp has effected a great change among the people—whether for their advantage or not is a question not yet decided. I was informed in Canna that if kelp keeps its present price Mr. MacDonald, of Clanranald, will make 6,000 pounds sterling by his kelp and Lord MacDonald no less a sum than 10,000 pounds."

During the course of the late war kelp rose to 18, 20, and even 22 pounds per ton in consequence of the interruption to the importation of *barilla*, and the profits upon it during that period were enormous. The price has subsequently fallen, by degrees, to 5 guineas per ton, and the sale has latterly been heavy even at that rate. This was to be attributed at first to the superior quality of the Spanish *barilla* for the purposes of glass making and soap boiling, but more recently to the almost entire removal of the duty on muriatic acid, or common salt. The rock salt of Cheshire, which now bears an insignificant price, is submitted to a chemical process, by means of which the soda is separated from the muriatic acid, and this is found to answer so completely as a substitute for kelp (which is an impure carbonate of soda) that the great glass manufactories of Newcastle are supplied with soda thus prepared. So pernicious, however, are the fumes of the muriatic acid gas which issue from the

soda works that vegetation is destroyed to a considerable distance, and the proprietors have been compelled to purchase the ground in their immediate neighborhood.

The number of people that find occupation in the manufacture of kelp is so great that a permanent interruption to the trade would be a serious evil. In the Orkney Islands alone the number of hands, according to Mr. Peterkin, who has obligingly furnished me with information on this subject, probably amounts to 20,000, for all the rural population is more or less employed in the business during the kelp season. Such being the case, it is gratifying to find that that public-spirited body, the Highland Society, is exerting itself to procure exact information about the qualities of kelp as a manure.

The rise and decline of the kelp industry in Scotland brought about great interest and gave rise to a series of prize essays and other papers published in the Transactions of the Highland and Agricultural Society of Scotland. Two prize essays on kelp were published by the society in Volume I of the second series, whose title-page bears the date of 1816. The first, by Rev. Dr. Walker, was delivered to the society in 1788, and contains much material on the rise and progress of the manufacture of kelp in the north of Scotland and is a valuable source of information of the period from 1720 to 1788. The second, "On the art of making kelp and of increasing the growth of marine plants from which it is made," by Angus Beaton, also gives much material on the subjects indicated, while the third article is a reprint of "Observations on kelp," by Robert Jameson in his Outline of the Mineralogy of the Shetland Islands and of the Island of Arran, published in 1798. In Volume V of the second series is a "Second report by the committee of the Highland Society upon the manufacture of kelp" (made in 1817), an "Essay upon the comparative value of kelp and barilla," by Andrew Fyfe. Other articles followed, until in Volume II of The Quarterly Journal of Agriculture (November, 1829–February, 1831, on p. 927) is a discussion of the then recent orders in council reducing the duty on barilla which so disastrously affected the kelp industry in the British Isles.

The effects in the highlands and islands of Scotland of the diminishing of the kelp industry, together with other causes, led to the great destitution of food of the years 1836 and 1837, and is ably discussed by Alexander Macgregor in the Quarterly Journal of Agriculture for 1838–39 (Vol. IX; pp. 159–199).

The conflict in France between the gatherers of seaweed for manure and those burning it for the ash to be used for soap and glass making, alluded to previously, was adjusted so far as possible by Colbert in an ordinance of 1681, reserving the living seaweeds (*Goémon*) to those living adjacent and leaving the seaweed cast ashore to those obtaining it first, to dispose of as they desired. The royal decrees of 1751 and 1772 authorized burning only during three months of the year. These various decrees simply emphasize the importance of the seaweed supply of northwestern France, but the subject is capable of more extensive treatment than seems necessary in this place.

The kelp manufacture as a supply of soda for soap and glass waned under the influences of the improved sources of obtaining this from Barilla and from salt. As a supply of potash for fertilizer it was essentially driven out by the introduction of guano and the discovery of the potash deposits at Stassfurt in northern Germany.



## POTASH FROM KELP.

Balch (1909) has investigated the composition of the bulb kelps, *Nereocystis luetkeana* and *Pelagophycus porra* of the western coast of the United States, and finds them rich in potassium salts. He estimates that—

One ton of thoroughly air-dried kelp, in addition to valuable by-products, volatile and nonvolatile, may be depended on for a minimum yield of 500 pounds of pure potassium salts, and 3 pounds of iodine. These are worth above \$20 in the markets, and the presumptive value of the several by-products should warrant the statement that the average yield of a ton of air-dried kelp may be stated at \$25, an average which is far more likely to be exceeded, especially as regards iodine, than reduced in quantity or value.

## IODINE FROM KELP.

After the separation of iodine in 1812 from the ash of "kelp" until comparatively recently kelp ash or kelp liquor has been the only, or at least the main, source of iodine. Kelp burning proceeded in Scotland, in Ireland, in France, and in Norway to supply this important product. Kelp burning proceeded in Scotland in much the same fashion that it did when soda was the important product. We find, e. g., in the Transactions of the Highland and Agricultural Society of Scotland (volume with title-page date 1849) a prize essay by Donald M'Crummen, "On the manufacture of kelp" (pp. 75-78), which deals with this matter, and again (in the volume whose title-page bears the date of 1853, pp. 448-456) articles—one on the analyses of the ash of three of the seaweeds (one of them *Laminaria digitata*, incl. *L. hyperborea*) by John Yeats, and another by Dr. Thomas Anderson, entitled "Observations on the possibility of improving the quality of kelp," in which the matter of iodine is the important substance. The methods of burning the seaweeds used so as not to lose most of the iodine, as was the case when the old method used for soda production was superseded and even a new method of obtaining it from the liquor coming from the plants, was proposed and to some extent adopted. The species of seaweed, too, and the season of collection make a difference in the product. Most, if not all, seaweeds contain iodine. Certain of the more delicate red seaweeds, when prepared as specimens on white paper containing starch, show this by turning the paper blue where liquid exudes from them. The principal seaweeds used in the preparation of iodine commercially have been the rockweeds or Fucaceae and the digitate species of *Laminaria*. The latter are found to contain the greater percentage. It seems to be true that the older plants contain more than the younger plants and those growing in deeper water more than those living in the littoral zone. The iodine-rich kelps are to be distinguished by their darker color, so far as known, turning black on drying. They, or at least some of them, have a peculiar penetrating odor when fresh. Foslie (1884, p. 53), speaking of the *Laminaria hyperborea* of the Norwegian coast, says that there are three iodine-manufacturing establishments on the coast between Trondheim and Bergen which make use annually of several hundred tons of ashes which consist, in the main, of burned plants of this species. There seems to be reason for believing that certain non-European species of *Laminariaceae* contain even a greater proportion

of iodine than the European. Hooker (1845, p. 153) states that *Lessonia nigrescens* of Cape Horn and the Falkland Islands and other Antarctic algae are shown by analyses to be peculiarly rich in iodine. There is a considerable manufacture of iodine in Japan (cf. Hugh M. Smith, 1905, p. 161) in the Island of Hokkaido. It is obtained from about 10 species of the Laminariaceae distributed through three or four genera. Several are species of *Laminaria*, and there are species of *Eisenia* and *Ecklonia*. The output of crude iodine in Hokkaido in 1901 was 12,405 pounds, valued at \$15,866.

The more recent manufacture of iodine from Chile saltpeter, however, has made the manufacture of iodine from kelp unremunerative. However, the Chilean supplies are not inexhaustible, and it may not be long before a return to the kelp and seaweed supply may be warranted.

#### OTHER PRODUCTS OF LAMINARIACEAE.

Besides the soda, potash, and iodine, there are other products of kelps, viz, algin, cellulose, dextrine, and mannite. Algin seems the most important. It was discovered by Stanford, and his account of it and its applications is adapted by Hugh H. Smith (1905, pp. 177-179) in his report on the "Utilization of Seaweeds in the United States." It is obtained from *Laminaria digitata* as a neutral, glazy, colorless fluid. When carefully filtered and precipitated by hydrochloric or sulphuric acid, the alginic acid is obtained, which, after being washed, may be compressed into a cake resembling new cheese. The alginic acid may, upon being dissolved in sodium carbonate, form a soluble sodium alginate used in a 2 per cent solution.

Algin and its salts appear to have a wide range of usefulness. Smith (loc. cit., p. 179) says:

Algin and its salts appear to have a wide range of usefulness. Some of these are indicated by Stanford (l. c.). Thus, as a sizing for fabrics, algin supplies the great desiderata of a soluble gum with marked elastic and flexible properties, and of a soluble substitute for albumen which can easily be rendered insoluble and used as a mordant. As a stiffening and filling agent, algin has an advantage over starch in that it fills the cloth better, is tougher and more elastic, is transparent when dry, and is not acted on by acids. It imparts to fabrics a thick, elastic, clothly feeling without the stiffness caused by starch. An additional advantage, possessed by no other gum, is that algin becomes insoluble in the presence of dilute acids; and, furthermore, no other gum has anything like the viscosity of algin; hence it is the most economical for making solutions for sizing. The alginate of aluminum in caustic soda makes a stiff dressing; in the crude unbleached state it is a cheap dressing for dark goods, and in the colorless state for finer fabrics. A glossy, insoluble surface results from the use of ammoniated alginate of aluminum.

Sodium alginate has been used for fixing mordants, and is a substitute for the various salts now used in precipitating mordants previous to the dyeing of cottons and yarns. For resolving and preventing the incrustation of boilers, sodium alginate has been pronounced by experts to be one of the best preparations, precipitating the lime salts in a state in which they can readily be blown off.

The charcoal formed during the manufacture of iodine by the wet process, when combined with algin, has been largely used for covering boilers, under the name of carbon cement. Three per cent of algin is sufficient to make the charcoal cohere, and a cool, light, and efficient covering is formed.

As an article of food algin has been suggested for thickening soups and puddings, and as a substitute for gum arabic in making lozenges and jujubes. It contains about the same percentage of nitrogen as Dutch cheese, and has a faint, pleasant flavor best expressed by "marine." In pharmacy it has a place in the emulsifying of oils, as an excipient in pills, and for refining spirits.

The dried stipes of certain species of *Laminaria*, particularly of *L. hyperborea*, are used on the coasts of France and Norway for fuel, and those of certain of the digitate *Laminariae* are, according to Farlow (1876, p. 717), used by surgical-instrument makers in the manufacture of sponge tents. Agarum is said by de la Pylale (1825, p. 177) to have been used on the Siberian coast as an antiscorbutic. Greville (1830, p. xx) relates that "the stems of a plant of the family *Laminariaceae* are sold in the shops and chewed by the inhabitants of South America wherever golter is prevalent. \* \* \* This remedy is termed by them *Palo Coto* (literally, golter-stick).

Paper has been made of, or with the assistance of, the cellulose of members of this family. Knife blades are forced into the stipes of certain species of kelps when fresh, and when dried are thus fixed firmly in a hard, tough handle which, contracting in drying, gives a roughness and the appearance of staghorn. Greville (1830, p. 29) quotes Dr. Neill as saying that this is done in Scotland with stipes of *Laminaria digitata*, and Hooker (1845, p. 152) says the same thing is done in South America by the Gauchos with stipes of the *Lessoneae*. In Japan, according to Yendo (1902, pp. 8 and 9), *Laminaria radicata* and *Eisenia bicyclis* are used along with *Sargassum*, one of the *Fucaceae*, for festoons and decorations, especially on New Year's Day.

In southern California the larger kelps, particularly *Pelagophycus porra* and *Macrocystis*, are tanned by a certain process and made into canes and various fancy objects and sold to tourists in considerable number as curios.

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APPENDIX L. *not in 11*

ECOLOGICAL AND ECONOMIC NOTES ON PUGET SOUND KELPS.

The word "kelp" is used in several different senses. By many persons it is used to designate all large blackish seaweeds. During the early part of the nineteenth century, when the kelp industry was flourishing in Ireland and Scotland, the term was used for the calcined ashes of seaweeds that found certain uses in the manufacture of glass and of potash fertilizers. At the same time the word was used to a certain extent to include all seaweeds from which these ashes were obtained. In the Puget Sound region at the present time navigators commonly use the term kelp to refer to the largest and most abundant brown seaweed of the region—the bladder kelp, *Nereocystis luetkeana*. The most definite sense in which the word is used is to include all plants belonging to one of the families of brown seaweeds—the Laminariaceae. It is in this sense that the word will be used in this paper.

"Seaweeds" is a general term for marine algae. Algae are relatively simple plants, lacking true differentiation into root, stem, and leaf, and being reproduced by spores, never by seeds. A spore is a simple reproductive body, usually consisting of a single cell and differing from a seed in not containing a ready-formed embryo plant. The algae are distinguished from their nearest relatives, the fungi, by the presence in their cells of chlorophyll, or "leaf green," which enables them to manufacture carbohydrate food, such as sugars and starches, from the two raw materials, water and carbon dioxide. This green substance gives the characteristic color to the green algae (Chlorophyceae). In the blue-green algae (Cyanophyceae) the chlorophyll is mixed with a bluish pigment. In the brown algae (Phaeophyceae) the green is almost completely masked by a brown pigment, and in the red algae (Rhodophyceae) by a red pigment. The real basis for the division of the algae into these four subclasses is certain differences in their method of reproduction, but the colors—green, brown, and red—correspond so closely with these differences in reproduction that it is usually, though not always, possible to assign an algae to its proper subclass merely on the basis of color. The pigment disappears quickly from some of the brown algae (e. g., *Desmarestia*) when they are taken from the water and exposed to the sunlight, leaving the green. In some of the red algae (e. g., *Rhodymenia*) spots are found when the plants are first removed from the water where they have no red pigment at all, but show only the green color.

The simplest kelps are leaflike in form, but are much larger than the leaves of ordinary plants. All kelps are leaflike when they are very young, but by a considerable differentiation of tissues many

of the species become, in maturity, rather complex in external appearance as well as internal structure. In the Puget Sound region (using the term "Puget Sound" to include the entire region from Cape Flattery on the west to Point Roberts on the north and Olympia on the south) the kelps vary in length from less than 2 feet in the case of the treelike sea palm (*Postelsia*) to a little over 70 feet in the case of the bladder kelp (*Nereocystis*). The leaf-like forms vary in length from a little less than 3 feet in the case of *Pleurophyucus* to 10 or 12 feet in the case of *Laminaria*. Mac-Millan reports *Nereocystis* as reaching a length of 100 feet at Port Renfrew, British Columbia. Setchell reports that he paced a *Nereocystis* plant at Carmel Bay, Monterey County, Cal., and found its length to be "41 good paces." This should be about 123 feet. Mertens, in 1829, reported the length of the stipe of a bladder-kelp plant in Alaska to be 45 fathoms (270 feet). A specimen collected by S. M. Zeller at the Puget Sound Marine Station in July, 1911, measured 72 feet. The author estimated many kelp in the vicinity of Friday Harbor during the summers of 1908 and 1910, and in various parts of Puget Sound in 1911, by pacing them. In no case did he find one exceeding 70 feet, while average specimens were usually found to be from 40 to 50 feet. *Macrocystis* is commonly said to produce the longest stems known in the plant kingdom, measurements of 1,000 feet having been reported. The longest specimen of this plant measured by the author was 40 feet. Saunders says that he has measured many fully developed specimens of this plant on the coasts of California, Oregon, Washington, and Alaska and has never found one exceeding 70 feet in length.

Various ecological factors determine the distribution of the different kelps. The most important of these factors are light, depth of water, the rise and fall of the tide, wave impact, tidal currents, and opportunity for anchorage. It is to be borne in mind that all of these factors have more or less influence and no one of them alone determines the distribution in any case.

The necessity of having light to enable them to manufacture carbohydrate food seems to almost completely bar the kelps of the Puget Sound region from water that exceeds 16 fathoms in depth, and to make them rare in water deeper than 8 or 10 fathoms. This statement has reference to kelps growing on the bottom and not provided with floats to keep any part of the plant near the surface of the water. Plants of this kind are much more common just above and just below low tide than at any other depth. Such kelps as *Nereocystis* and *Macrocystis*, being provided with floats that keep their fronds near the surface of the water, are dependent upon the light factor at the bottom of the water only when they are very young. These two kelps are quite commonly found in water from 3 to 5 fathoms deep—sometimes in 6 fathoms or more of water.

The rise and fall of the tide determines the position in which several of the kelps grow. *Postelsia* (the sea palm), *Hedophyllum*, and *Pleurophyucus* are examples of this. Wave impact, however, is also a factor in the distribution of all of these, for they are confined to situations where the waves are rather violent. *Pleurophyucus* is sublittoral, while *Postelsia* and *Hedophyllum* are littoral. *Postelsia* is confined to areas of exceptionally heavy surge.

*Nereocystis* is an example of a plant never found growing in quiet water. It is confined to situations where it is subjected to strong tidal currents. Submerged plants must get their oxygen for respiration and their carbon dioxide for the manufacture of carbohydrate food from the air in the water. The demand for these gases is large in the case of these rapidly growing kelps, and there is, of course, much more air in water disturbed by wind or tidal currents than in quiet water.

All of the kelps are attached to some solid object, such as rocks, stones, shells, piling, and logs, by means of a more or less differentiated holdfast. In some cases (e. g., *Cymathæra*) this holdfast is a mere disk. In other cases (e. g., *Laminaria* and *Nereocystis*) the holdfast is larger and is much branched. Many of the kelps that grow in the littoral and upper sublittoral zones are attached to the solid rock of the shore. This is the case with *Postelsia*, *Hedophyllum*, and *Pleurophycus*. *Laminaria* and *Costaria* are frequently found on piling. Kelps growing in deeper water are quite commonly attached to small stones or to old shells. *Laminaria* and *Agarum* are examples of this. *Nereocystis* is usually attached to heavier stones or large pieces of rock. Kelps are not found on muddy or sandy bottom unless there are firm objects there to which they can attach themselves. Blind Bay, on the north shore of Shaw Island in the San Juan group, has a very heavy growth of *Laminaria*, *Agarum*, and other leaflike kelps on a mud bottom, the anchorage being principally on the shells of dead bivalves. The water in this bay is quiet, so that the plants can keep their position by anchorage to comparatively small objects.

Kelps, as already stated, are reproduced by spores. These spores are microscopic in size and are usually composed of a single cell. They are zoospores, or "swimming" spores. It is comparatively easy to tell when a large kelp is "fruiting" by merely examining the surface of its fronds with the naked eye. If it is "in fruit" irregular patches, differing in color from the rest of the frond, will be readily seen. On feeling of these soral patches it will be found that they are somewhat thicker and firmer than the other parts of the frond. In these soral patches there are numerous sporangia, and in these sporangia the spores are developed. These spores swim about for a short time by means of cilia, and, when they find a favorable place, settle down and quickly develop into young kelps. The growing region of all of the kelps discussed in this paper is at the place where the stipe and frond join. The fronds, then, increase in length at the base, and the same region of meristematic tissue that contributes to this basal growth of the leaflike part of the plant extends also to the upper part of the stipe, and there causes the lengthening of the stem-like portion.

There are 12 genera of kelps found in this region in sufficient abundance to merit discussion in this paper. They are *Laminaria*, *Hedophyllum*, *Cymathæra*, *Agarum*, *Pleurophycus*, *Alaria*, *Costaria*, *Postelsia*, *Pterygophora*, *Egregia*, *Macrocystis*, and *Nereocystis*. So far as commercial possibilities are concerned, *Nereocystis* is much the most important of these because of its great size, its abundance, and the ease with which it may be harvested in large quantities by labor-saving devices. Five other genera of kelps (*Lessonia*, *Chorda*,

Eisenia, Dictyoneuron, and Thalassiophyllum) have been found by MacMillan on the southern shore of Vancouver Island, and it is possible that they may be found occasionally on our own shores. Several genera of algae not included among the kelps also deserve mention. Two of these genera (Fucus, commonly called rockweed, and Desmarestia) belong to the brown algae. Four others (Ulva, called sea lettuce; Monostroma, Enteromorpha, and Codium) are green algae. The last is Rhodymenia, a red alga. It is called dulse in some European countries.

The plants of the genus Laminaria consist of a distinct stipe with a branched holdfast and a broad leaflike frond without a midrib. The largest ones found in the Puget Sound region are about 10 feet long and perhaps 2 feet in width. Saunders reports *Laminaria saccharina* as reaching a length of 26 feet in Alaska. In Japan Laminaria plants are reported to reach a length of 100 feet. All of the Laminarias contain mucilage ducts and their surfaces are quite mucilaginous. The Laminarias are found mostly below low tide, although on rocky shores some of the plants are exposed at extreme low tide. They are often dredged in water up to 15 fathoms deep.

Two species of this genus are very common in the Puget Sound region, *Laminaria saccharina* and *Laminaria bullata*. *L. bullata* is darker in color and firmer in texture and thicker than *L. saccharina*. Its surface is also covered with large symmetrical "dents" called bullæ, while that of *L. saccharina* is more regular. *L. bullata* is peculiar to the Pacific coast of North America. *L. saccharina* is found in the North Atlantic as well as in the Pacific.

There are several forms of each of these species, but they are based on minor differences and are not important for the purposes of this paper. These two species are common throughout the San Juan Islands and are widely distributed in the Puget Sound region. They are quite commonly anchored to stones, although sometimes old clamshells furnish anchorage for them, and they are found to a considerable extent on piling and on timbers of floating docks. Like other kelps they are absent from sandy bottoms except where stones, shells, or other firm objects furnish anchorage.

A third species, *L. andersonii*, is found on the wave-swept shores near Cape Flattery, and has also been found by Gardner on rocks in the upper portions of the sublittoral zone on the west coast of Whidby Island.

The term "devil's apron" is applied to several of the large leaf-like brown algae, especially those of somewhat blackish appearance. It is perhaps most commonly used to refer to *Laminaria bullata*.

The genus Hedophyllum differs from the genus Laminaria in having no stipe. The fronds are sessile. Like those of Laminaria they have no midrib. They are frequently bullate at the base. Their fronds do not reach so great a length as those of Laminaria, 2½ feet being the extreme length observed by the writer. The plants of this length were found on rocks in the littoral zone near Neah Bay, where they are so abundant as to form almost the entire covering of the rocks in places. It is also common, although smaller, on the west shore of San Juan Island and on Turn Rock, near Friday Harbor. This genus does not usually anchor itself to small stones, but prefers the solid rock. Only one species of this genus is common in the Puget Sound region. This is *H. sessile*. This species is

peculiar to the Pacific coast of North America. *H. subsessile* was reported by Saunders as being found in Puget Sound, but the writer has not seen it.

*Hedophyllum* fronds do not spread out flat, but tend to form a head somewhat resembling a head of cabbage. This appearance is much more evident in the plants of comparatively quiet places, such as Turn Rock, than it is in the plants of the Neah Bay region and of the west shore of San Juan Island, where the wave impact is heavier.

The plants belonging to the genus *Cymathaere* are usually clean, trim-looking plants attaching themselves to rocks and small stones in the sublittoral zone. They are sometimes dredged in 2 or 3 fathoms of water. The plant is leaflike in form. The stipe is only a few inches long, but the frond sometimes reaches a length of 6 or 8 feet. They are attached by a disklike holdfast. There is no midrib, but a triplicate longitudinal fold extends through the middle of the frond. This characteristic gives the specific name *triplicata* to the single species found in this region. The plants are of lighter color than those of any other genus of kelps of this region. At least at the base they are thicker and firmer in texture than the other leaflike kelps. From the middle upward the frond is sometimes thinner, and its margins are then wavy. This characteristic seems to be more common in plants exposed to rather violent waves, while those that grow in quieter water are of more nearly uniform thickness throughout and do not have wavy margins. The writer has found *Cymathaere triplicata* in the greatest abundance at Neah Bay and at Kanaka Bay. In both of these places the wave impact is violent, and the plants are mostly of the thin type. In the channel between Turn Island and San Juan Island, near Friday Harbor, plants of this species are dredged in large numbers in 2 or 3 fathoms of water. These plants are attached to small stones on a sandy bottom and are of the thick type. *Cymathaere triplicata* is a gregarious species. It is peculiar to the Pacific coast of North America.

The genus *Agarum* is represented by a single species (*A. fimbriatum*) in the Puget Sound region. This species is leaflike in form, but differs from the three preceding genera in having a midrib. The plants are somewhat shorter than those of *Laminaria*. The stipe is very short, and both the stipe and the frond are fimbriate on the edges. This species has a branched holdfast similar to that of *Laminaria* and *Hedophyllum*. It is commonly found growing with *Laminaria saccharina* and *L. bullata*. *Agarum fimbriatum* is not found commonly outside of the Puget Sound region.

*Pleurophyucus gardneri* is a dark-colored, leaflike kelp. It grows in the upper sublittoral zone and is confined to regions of rather violent waves. The upper end of the frond is usually somewhat torn by being beaten against the rocks upon which it grows. The holdfast is branched. The plants do not usually reach a length of more than 30 inches. The stipe is longer in proportion to the length of the frond than it is in *Agarum*. There is apparently a very broad midrib, but this is not a true midrib. It is really a very broad, shallow furrow on one side of the frond with a correspondingly prominent flat ridge on the other side. The production of spores is confined to this furrow. The frond, outside of this furrow, is lunglike in texture. This plant occurs in great abundance at Neah Bay and a few specimens have been found on Long Island and on the coast of San



**Juan Island at Kanaka Bay.** There is one species of this genus in the Puget Sound region, and it is found only on the Pacific coast of North America.

The plants of the genus *Alaria* differ from the other leaflike kelps of the region in the fact that the sporangia do not form soral patches in the frond, but are confined to special leaflike sporophylls situated on the stipe below the base of the frond. These sporophylls vary from a few inches up to more than a foot in length. There are sometimes as many as 65 of them on a single plant, although the number is usually much smaller. *Alaria valida*, a very common species in Puget Sound, has a ribbonlike frond reaching a length of 10 or 12 feet, with a very prominent midrib and wavy edges. It is found in the sublittoral zone. An *Alaria* found in great abundance at Neah Bay has a frond that is lunglike in texture, like that of *Pleurophycus gardneri*. MacMillan reports *Alaria* as reaching a length of 50 feet at Port Renfrew, British Columbia.

*Costaria turneri* is the only representative of the genus in Puget Sound. It is found in much the same habitat as *Agarum* and the *Laminarias*. It is sometimes found growing on the holdfast of *Nereocystis*. It has a branched holdfast, a rather short stipe, and a broad frond with five ribs. Three of these ribs are prominent on one face of the frond and two on the other. Where a rib is prominent on one face of the frond there is a corresponding depression on the other face. The frond does not present a plane surface between the ribs. Perhaps the term "shirred" as it is used in sewing expresses its condition best. The plant is of about the same size as *Agarum fimbriatum*. It does not show this shirred appearance when young.

The "sea palm," *Postelsia palmaeformis*, grows in dense clusters in the littoral zone on rocks that are exposed to waves of unusual violence. The plants are less than 2 feet high and consist of a hollow rubbery stipe of very great flexibility crowned by a dense cluster of slender, flattened, longitudinally corrugated, leaflike fronds. The writer has found this species only on Tattoosh Island and on the rocks of the mainland near Cape Flattery. It does not extend around to the quieter waters of Neah Bay as most of the algae of that vicinity do. This plant is not found north of Puget Sound. It is found southward as far as Point Sur on the California coast.

The genus *Pterygophora* is represented by a single species, *P. californica*. The plant consists of a rather massive stipe anchored by a powerful holdfast and bearing at its summit a number of fronds from 1 to 2 feet in length. One of the fronds is terminal while the others are pinnately arranged on the edges of the stipe, which is somewhat flattened at its top. The writer found stipes of this plant at Neah Bay reaching a length of 7 feet and a diameter of 2 inches. The stipes are distinctly woody when they first come from the water and are horny when dry. They are perennial and show distinct rings in the stem, looking to the naked eye very much like the annual rings of dicotyledonous and gymnosperm trees. Under the microscope, however, they differ quite materially from these. These plants are quite commonly cast up on the beach at Neah Bay. The writer has not seen them elsewhere in this region.

*Egregia menziesii* is sometimes called the feather-boa kelp from its fancied resemblance to a feather boa. It is found in the lower

littoral and upper sublittoral zones in regions of violent wave impact. It attaches itself to rocks by a powerful holdfast, from which as many as 25 branches arise. These branches reach as much as 20 feet in length. Each one is flattened, and is stout and leathery. It has two kinds of outgrowths along its edges—slender sporophylls, reaching a length of 2 or 3 inches; and hollow floats of about the same length, with a thickness of perhaps three-quarters of an inch. This plant is found sparingly at Kanaka Bay, but is very abundant along with *Nereocystis* and *Macrocystis* at Neah Bay. There is only one species of this genus in the Puget Sound region.

*Macrocystis pyrifera* grows in considerable abundance in the vicinity of Cape Flattery and Neah Bay. The writer found pieces of this plant floating at Port Crescent. The stipe is slender and rope-like. Several stipes arise from a single large branched holdfast. Along the stipe appear the flat wrinkled fronds, each with a hollow float, or pneumatocyst, at its base. These keep the upper part of the mature plant floating on the surface of the water. This plant usually grows a little closer to the shore than *Nereocystis* does, although both it and *Egregia* are somewhat mixed with the beds of *Nereocystis* at Neah Bay.

*Nereocystis luetkeana* is the most abundant kelp of the Puget Sound region. The huge size of the individual plants, the fact that its bladderlike float is always at the surface of the water, where it can be seen, and the fact that it forms dense beds covering such large areas, bring it to the attention of every observer who crosses the waters of Puget Sound. It attaches itself to stones, and reaches its best development in water that is 8 or 10 fathoms deep. The holdfast is large, and from it there extends upward a cordlike stipe about half an inch in diameter, gradually enlarging into a hollow portion, known as the pneumatocyst, which terminates in a hollow bulb, upon which are borne two tufts of slender ribbonlike fronds, sometimes attaining a length of 20 feet or more. The length of this plant is discussed earlier in this paper. The word "kelp," as used by the seafaring men of the Puget Sound region, means this one species, the other large brown algae being referred to as seaweeds. It is also called bladder kelp and sea-otter's cabbage. At high tide the pneumatocyst stands straight up, with its knoblike end projecting a little from the water. At low tide several feet of the pneumatocyst lies on the surface of the water. In either position the fronds are always entirely submerged in the water, and float out parallel to its surface. The largest beds of this plant are found on exposed shores, where violent wave action accompanies strong tidal currents, but narrower beds of almost equal density are found on rocky ledges along shores swept by strong tidal currents. Considerable areas are sometimes found on ledges in open water. Such a patch of kelp is found west of Browns Island, near Friday Harbor. A larger bed is found on Partridge Reef, west of Whidby Island.

*Nereocystis*, like the other Laminariaceae, shows a considerable differentiation of tissues. The stipe shows cortex, central cylinder, sieve tubes, and a cambial layer, from which increase in thickness takes place. In the pneumatocyst area there are two cambial layers, an inner one and an outer one. The region of elongation in this plant extends over the pneumatocyst and the bases of the fronds. During the summer of 1911, at the Puget Sound marine station, S. M. Zeller

removed the fronds from several *Nereocystis* plants, and in every case the plant soon died. Possibly this means that the fronds are similar to the leaves of higher plants in performing the functions of respiration and photosynthesis. This view is consistent with the presence of sieve tubes in the stem, which are evidently for the transfer of manufactured food downward. It thus seems that there is an amount of localization of function in this plant that is comparable with the condition in seed plants.

This plant is reproduced by spores developed in unilocular sporangia. These sporangia, together with sterile processes, called paraphyses, form soral patches upon the fronds. These soral patches are common on the fronds in June, July, and August. Zeller has noted, in an unpublished paper, that these patches fall out when the spores in them are mature. As in the case of the other kelps the soral patches are readily found by the fact that they differ from the other parts of the frond in color, thickness, and texture. They are readily seen on the fronds in the water as one passes near them in a small boat. Judging from the large extent of the soral patches, it is likely that spores are produced in enormous numbers.

It seems probable that the spores settle down soon after they are discharged from the sporangia and begin at once to develop into new plants. Frye has observed by means of a glass-bottomed bucket that young plants a few feet in length are seen on the bottom in March. The plant seems to be an annual, the new crop starting before the old one disappears. Bladder-kelp plants begin to drift loose in September and when winter comes the beds are entirely broken up. In case any economic use is made of the bladder kelp it is evident that it should be harvested in the latter part of the summer, beginning perhaps July 15. It can be harvested at that time of the year without interfering in any way with the next year's crop.

In order to arrive at an estimate of the tonnage of bladder kelp available in Puget Sound waters the author has used the following method: A light wooden frame 4 feet square was made, and this was laid down upon the kelp bed and the number of plants whose floats were included within the area of 16 square feet was thus determined. This was done repeatedly in different beds and the results were averaged. It was found in this way that in the beds of maximum density there are 1.25 plants to the square foot. Fairly dense kelp beds vary from this down to 0.75 plant per square foot. In the thicker beds the plants do not usually grow singly, but are found in groups of from 5 to 25, in which they are frequently much twisted together and entangled. Occasionally very thin beds of kelp are found. In some of them the writer has estimated as low as 0.025 plant per square foot.

Having arrived at an estimate of the number of kelp per unit of area in various beds, the next step was to weigh some plants. Mature specimens from average beds were found to weigh from 18 to 35 pounds. In the very dense beds nearly all of the kelp will approximate 30 pounds. These are the weights as taken in most cases within an hour or two after the plants were taken from the water. In the computations used in making the estimates in this paper, 30 pounds per kelp was the weight used for the very dense beds and 20 pounds for the lightest beds.

Being able now to estimate the number of kelp per unit of area and the weight of the individual plants, there remained only to determine the length and width of a bed in order to estimate the number of tons of kelp in it.

By the method here outlined the following estimate of the amount of bladder kelp (*Nereocystis luetkeana*) in the Puget Sound region was made:

	Tons.
1. Smiths Island-----	100,000
2. American shore of the Strait of Juan de Fuca-----	85,000
3. San Juan Island and small islands near its shore-----	10,000
4. Other islands of the San Juan group-----	9,000
5. Admiralty Head to Point Roberts-----	5,000
6. Puget Sound from Port Townsend to Olympia-----	1,000
	<hr/> 210,000

Persons who have observed the kelp beds in this region for years uniformly report that there is but little variation in the kelp crop from year to year. It is evident that in case the crop were harvested at the proper time each year the yield would be practically the same year after year.

Excepting in the vicinity of Neah Bay the kelp beds are what the foresters would call a "pure stand." That is, they are unmixed with any other plants that are of sufficient size to be of any importance. The fact that the bladder kelp has successfully solved its own problem of adapting itself to its environment has resulted in a host of smaller plants attaching themselves to the kelp in order to get the benefit of the advantageous situation in which it lives. The interest attaching to these is, however, wholly ecological and not economic. In case the kelp beds near Neah Bay were harvested for any purpose two other species, *Macrocystis pyrifera* and *Egregia menziesii* would be somewhat mixed with the material obtained. In some parts of the beds nearest the shore the combined quantity of these two species would probably about equal the quantity of bladder kelp that would be harvested with them.

*Fucus*, commonly called "rockweed," is very common in nearly all parts of the Puget Sound region on rocks in the littoral zone. *Fucus* is not a kelp in the sense that that word is used in this paper. It is a brown alga, belonging to the family Fucaceae. It has sexually-produced spores, while those of the kelps are produced asexually.

In *Fucus* plants there is no sharp distinction of stipe and frond. The base of the plant is almost cylindrical, but the transition from this to the flat part of the thallus is gradual. The plants are leathery and are anchored to rocks or other objects by a disklike holdfast. The plants are very mucilaginous. The spores are produced in minute cavities, opening upon the surface of the swollen tips of the plant. The opening of each cavity (conceptacle) is slightly elevated so the fruiting area has a somewhat pimply appearance. These plants are found at all seasons of the year, the crop seeming just as abundant in the winter as in the summer. Their growth is dense in places, forming a very thick, slippery covering on the rocks. Some *Fucus* plants of this region are narrow, while others are very broad. Some of them have long irregularly placed inflations near the tips and some lack these entirely. In some places the *Fucus* is very long and in others it is quite short.

*Desmarestia ligulata*, forma herbacea, is a brown alga, sometimes reaching a length of 8 or 10 feet and a width of from 12 to 16 inches, although it is usually much smaller than this. It is quite commonly dredged with *Laminaria* and other kelps. Large specimens are frequently found drifted on the beach at low tide. There is a distinct cordlike midrib, and a branch of this extends into each of the leaflike outgrowths that appear along the edge of the frond. The plants lose their brown color quickly when exposed to direct sunlight and become green. If they are placed in contact with other brown algae they cause them also to lose their color. The plants of this species have a very sour taste.

*Ulva*, *Monostroma*, and *Enteromorpha* are conspicuous grass-green seaweeds, very common in the littoral zone. The thallus of *Ulva* is two cells thick, while that of *Monostroma* is only one cell thick. *Enteromorpha* has the form of a tube instead of a flat thallus. Plants of these genera usually vary from a few inches to about 2 feet in length, but at Neah Bay one species of *Monostroma* reaches a length of 7 feet.

*Codium mucronatum* is a green alga. The thallus is cylindrical and much branched, the branches being of about the same size as a lead pencil. As a result of the repeated branching a dense mass of it of considerable weight grows from a single holdfast. It grows on rocks in the littoral zone where there are strong waves. It is found at several places in the San Juan Group, but the only considerable supply of it that the writer has seen is on Turn Island, near Friday Harbor.

*Rhodymenia pertusa* is a red alga, attached to stones and shells by a holdfast from which the thallus gradually widens into a somewhat leaflike form. The thallus is pierced by many holes. Among the San Juan Islands it is often dredged with the leaflike kelps.

The seaweed industry has reached its highest development in Japan. Several causes combine to produce this result. The population is dense, the coast line long and irregular, and the interior is mountainous. These conditions bring many of the Japanese people into close contact with the seashore. The skill and patience of the people in preparing articles by hand has doubtless assisted in making the seaweed industry an important one in Japan. In 1904 the Japanese prepared over \$2,000,000 worth of seaweed. Of this over \$600,000 worth was exported—principally to China and Korea. The writer has purchased at a Japanese store in Seattle eight different kinds of dried food prepared from seaweeds in Japan and shipped here for sale to the people of that country now resident in Seattle. The Japanese have not been content with harvesting the crop of seaweeds as they happen to grow, but they cultivate one species by sticking brush into the water for it to grow on. By this means they have increased the yield very largely. Seaweed in some form is a daily article of food in a large proportion of the Japanese homes.

In the United States the industry amounts to only about \$35,000 and is confined almost entirely to a single State (Massachusetts) and to a single species (*Chondrus crispus*, Irish moss).

As mentioned at the beginning of this paper, the seaweed industry was formerly an important one in Scotland and Ireland. The weeds in this case were used as a source of alkali for the manufacture of soap. The production of the seaweed ash from which this alkali was

obtained was the basis of the livelihood of about 60,000 people of the poorer class. The industry declined considerably because of competition with the production of alkali manufactured from common salt and seems to have been finally ruined in 1832 by the removal of the import duty on barilla. Barilla is the impure potash obtained from the ash of several species of flowering plants belonging to the genus *Salsola*. Several seaweeds are reported to be still used in Ireland as food. Some economic uses are also made of seaweeds in Hawaii.

The Japanese find economic uses for more than 50 species of their seaweeds. Among the commodities made from them are food, plaster, glue, isinglass, iodine, and starch. They also use them for manure for their rice fields. Their method of manufacturing iodine was reported by Davison in 1906 to be somewhat crude. He says that the Japanese Government was at that time supervising experiments on improving the yield. He gives the following figures for the export of potassium iodide for the years mentioned:

1902	-----	\$7, 210
1903	-----	50, 585
1904	-----	133, 400

The following genera of algae discussed in this paper and occurring in the Puget Sound region are known to have found important economic uses—*Laminaria*, *Cymathæra*, *Alaria*, *Nereocystis*, *Fucus*, *Codium*, *Rhodomenia*, *Ulva*, and *Enteromorpha*. In some cases the species used is the same one that is found here. In other cases it is a different species of the same genus. This does not purport to be a complete list of seaweeds having economic uses, but comprises merely a few selected for the purpose of showing what uses have been made of marine vegetation.

Among the Japanese several species of *Laminaria* are of commercial importance, but they are not the same species that are found in our region. Two species especially are important articles of food among the Japanese, and considerable quantities of them are exported to China for food. In 1894 Japan exported leaf *Laminaria* and cut *Laminaria* to the value of 607,000 yen, most of it going to China. The Japanese collect these plants by winding them up on poles and then cutting them loose at the base. They are spread upon the sand on the beach to dry and are then packed into bundles or bales for shipment. One kind is used in making confectionery and another kind is used in making tea and soup and is also cooked in other ways. *Laminaria* roll is a popular article of food among the Japanese. It is prepared by wrapping portions of fish in suitable sized pieces of dried *Laminaria* that have been boiled in fresh water and then boiling both together in dilute soy, soup, or milk. Another species of *Laminaria* is used by the Japanese for festoons at New Year's time.

The food products prepared from *Laminaria* are called "kombu." The manufacture of kombu in Japan dates back to 1730, and there has been but little change in the method of manufacturing it since that time. The city of Osaka is the principal center for the manufacture of kombu. In 1903 it had 45 kombu factories, each employing from 10 to 30 men, women, and children.

It is evident from the description and habitat of one plant used as a source of potash and iodine in Scotland in the early part of the

nineteenth century that it was a species of *Laminaria*. It is mentioned in the article as belonging to the genus *Fucus*, but this genus included at that time many plants that have since been assigned to other genera.

*Cymathæra triplicata* was indentified by Dr. N. L. Gardner as the alga from which a bundle of dried food material purchased by the writer at a Japanese store in Seattle was prepared. *Alaria* is also used as an article of food in Japan.

Several species of *Fucus* have been used in Ireland and Scotland as a source of alkali and iodine. The alkali was used as a fertilizer and in the manufacture of soap and glass.

*Codium mucronatum*, the same species that occurs in the Puget Sound region, is used as an article of food by the Japanese.

*Rhodymenia*, under the name of dulse, has been used for food in some European countries. *Ulva lactuca*, *Enteromorpha linza*, and *E. intestinalis* are species common in Puget Sound which the Japanese have found useful as food.

The Indians of the Pacific coast of North America have found several uses for the bladder kelp. The Alaska Indians formerly made fish lines of the long cordlike stipes by soaking them in fish oil and manipulating them to render them pliable. Bottles to contain the oil were made from the bulb and the adjacent hollow part of the stem by the same process. It is reported that the Indians in the San Juan Islands formerly prepared salt for use in food by spreading the fronds of this plant on clean logs and collecting the salt that effloresced on the surface of these fronds. The hollow part of the stipes was used by Alaska Indians as a worm in the process of distilling "hoochenoo," a dark-colored poisonous drink. Headache is cured by the Indians in Sitka by placing the smaller end of one of these tubes in the ear and the other against a hot stone to generate steam. Indians at Neah Bay still use the split bulb of this plant for application in cases of caked breasts. It seems to be soothing and antiseptic.

A patent is held by T. C. Frye and C. E. Magnuson, of Seattle, on a process of manufacturing from *Nereocystis luetkeana* substitutes for preserved citron, orange peel, lemon peel, and other candied and preserved products. The writer has tasted products prepared by their process and has found them very palatable.

It is learned that at Friday Harbor, Wash., and at Port Angeles, Wash., bladder-kelp plants have been cut up and used in gardens for fertilizer with excellent results. At Friday Harbor the method used was to collect the plants in the spring from the beach, where they had drifted in during the winter, and bury them in the garden at the time of planting seeds. At Port Angeles the plants are placed in the soil in the fall that they may decay during the winter.

Considering the abundance of the seaweeds in Puget Sound in connection with the large use that the Japanese make of their seaweeds, the question naturally arises as to whether there is a potential kelp industry here. As the first step toward answering the question we must consider how far our conditions are similar to those in Japan. The population in the Pacific Northwest is not over dense, and there is no congestion of population on the seashore. Americans certainly could not be advised to take up the slow and painstaking work of gathering seaweeds by hand and preparing them for food,

and the Japanese who have come to our shores have shown no disposition to do so. If a kelp industry is to be developed in the Puget Sound region, it must utilize a plant whose abundance and situation will permit it to be harvested in large quantities and by labor-saving devices. There is but one such plant in this region. This is the bladder kelp, *Nereocystis luetkeana*. The whole question of a possible kelp industry in this region rests on whether the chemical analysis of this plant shows that it contains valuable constituents in such form and quantity that they can be profitably extracted on a commercial scale.

A very thorough piece of work was done by J. Kendrick in Scotland in 1898 on the use and value of seaweed as manure. His work was done on several species of *Fucus* and *Laminaria*. He found the amount of water in the fresh plants to be from 70 to 83 per cent, and the amount of potash ( $K_2O$ ) to be from 0.92 to 1.69 per cent. He suggests 1.24 per cent as an average amount of potash in the plants on which he worked. His conclusion is that both analysis and field experiments indicate that these seaweeds are as good fertilizer for potatoes, weight for weight, as is dung. He finds, however, from the field experiments that to get the best results the seaweed should be supplemented with phosphates. Anyone interested in the kelp industry would do well to read in full his article in Volume X of the fifth series of The Transactions of the Highland and Agricultural Society of Scotland, pages 118-134. In his field experiments the fresh weeds were placed in the soil without any treatment. He observes that seaweeds treated in this way should have at least a few weeks to decay before they can be useful to the plants.

Thinking that some suggestion as to methods of harvesting and caring for this kelp may be of service to anyone considering this industry, the writer has given some attention to that subject. Diligent inquiry has been made among seamen of experience in this vicinity to secure such suggestions.

From all of the suggestions and information received the following somewhat general ideas are offered. A large flat-bottomed barge propelled by a stern paddle wheel would be the best type of boat to use. A heavy cutting bar should be fitted across the front of this and so attached that it could be readily raised or lowered. The depth at which the kelp should be cut would probably vary from 6 to 10 feet, depending upon the size of the kelp and the height of the tide. In the case of kelp weighing 30 pounds or more only about 3 or 4 pounds of material will be left in the sea if the plant is cut off 10 feet below the bulb. At high tide the cutting bar would have to run 10 feet below the surface of the water in order to cut them at this point. At low water, however, the bar could run much higher, since the hollow part of the stem would then be lying on the surface. The fronds always remain near the surface so that they will be obtained by cutting at any depth more than 4 feet. When cut loose the plants float. In order to hoist the mass of loosened plants onto the barge it is suggested that the cutting bar should be placed in such a position as not to interfere, and a huge scooplke rake should be lowered and by this means the kelp be rolled back onto the barge. This would involve backing the barge after a suitable amount of kelp has been cut loose, in order to get the rake under the mass of floating kelp.



Considerable quantities of driftwood are sometimes found in kelp beds, even large logs being sometimes entangled in the kelp and held there. This driftwood might in some cases prove somewhat troublesome in harvesting the kelp. It is more abundant in the kelp when the water is quiet than when it is disturbed by heavy waves or by swift tidal currents.

In other countries where economic use is made of seaweeds they are harvested by hand, so that there will be no foreign precedents to guide anyone who may engage in kelp harvesting. The only machinery that the writer has heard of for cutting plants under water is that used for cutting eel grass in the Erie Canal.

The larger kelp beds could, of course, be harvested most economically. The one at Smiths Island is about 1 mile square, and would be the easiest of all the beds to harvest. The beds at Kanaka Bay, on San Juan Island, and at Iceberg Point, on Lopez Island, and at Neah Bay, near Cape Flattery, are also of sufficient size and density to be readily harvested. At Neah Bay much rougher water would be encountered than in the other beds mentioned.

Kelp plants decay quickly in the summer if taken from the water and allowed to lie in piles. If well spread out they will dry in a few days in the sun to less than 20 per cent of their original weight, and a thick incrustation of effloresced salt will appear on the surface. It would not do to sundry this and then pack it into bales for shipment, as much of the effloresced salts would then be lost. A factory for making whatever products are found desirable could be located near enough to the large kelp beds so that the fresh material could be taken at once to the factory. In case it is found necessary to ship the dried raw material it should be packed in tight containers or bales, so that no salts will be lost. Burning the kelp on the beach near where it is collected and shipping the ash is also a possibility to be considered.

It would probably be best in beginning the harvest of kelp to leave a part of each bed, so as to insure the production of a sufficient number of spores to provide for the production of next year's crop. The writer does not believe this to be necessary, but it would be well to proceed cautiously in the beginning. By selecting an isolated bed and cutting all of the kelp in it some time after July 15, then observing whether kelp grows there the following year, a test could be readily made of whether a sufficient number of spores are produced before that time to insure the next year's crop.

It has been suggested that floating kelp and kelp cast up on the shore could be profitably used, but the observations of the writer do not indicate that either of these sources offers enough material to merit consideration for commercial purposes.

In some places, where the tidal currents and the depth of the water seem to be favorable for *Nereocystis*, vigorous plants are found, but they are very sparsely distributed, averaging in some cases even less than one plant to every 50 square feet. It seems possible that the thinness of these beds may be due to the lack of stones for anchorage. In case important uses should make this kelp valuable, it would be worth while to examine these bottoms to see whether there really is a scarcity of stones, and if this proves to be the case, to place stones there and see whether the kelp crop would be increased by this means.

The kelp bed at the south end of Guemes Island and the one on the Alden Bank would be good beds on which to experiment.

Dall reported in 1875 that there was a bed of "bullhead kelp" (*Nereocystis*?) 25 square miles in extent on a shoal in the open sea northeast of St. George Island, in the Bering Sea. Setchell and Gardner say that *Nereocystis luetkeana* is "plentiful in the attached condition from the Shumagin Islands, Alaska, to the region of Santa Barbara Channel on the California coast." The amount of kelp available from Alaska and the possibility of greatly increasing the yield on the thinner beds in the Puget Sound regions are important questions for future investigation.

If a kelp industry is to be developed in the Puget Sound region, the factories handling the material should not be limited to one product, but should be fitted to turn out all of the products that can be made from it.

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## THE KELPS OF THE CENTRAL CALIFORNIAN COAST.

## INTRODUCTION.

The western coast of North America, according to Setchell and Gardner (1903), may be considered as made up of four, possibly five, well-marked regions of algal growth. These are the following:

1. *Tropical region*.—The northern boundary is in the neighborhood of Magdalena Bay, Lower California. It is characterized by the absence of the Laminariaceae and the abundance of Sargassaceae, Dictyotaceae, and other tropical groups.

2. *Subtropical region*.—This region extends northward from Magdalena Bay to Point Conception, and is characterized by the presence of the Laminariaceae of warmer seas, such as species of *Eisenia*, *Pelagophycus*, and *Egregia* (*Egregia laevigata*, Setchell), by certain Dictyotaceae, as well as warmer water Rhodophyceae, all of which either have Point Conception as their northern limit, or occur only in warmer isolated areas above it.

3. *North temperate region*.—The northern boundary of this region is in the neighborhood of Puget Sound. It is characterized by the absence of the strictly subtropical Laminariaceae, except occasionally *Egregia laevigata*, Setchell. No Sargassaceae nor Dictyotaceae are found. Instead of these the Nereocystis of colder waters, the northern *Egregia* (*Egregia menziesii* (Turner) Areschoug), and certain northern species of *Laminaria* occur.

4. *Boreal region*.—The north temperate region passes into the boreal region at Puget Sound, and here many of the characteristic species are intermingled. An upper and a lower boreal region may possibly be distinguished. The region in general is characterized by the occurrence of *Laminaria saccharina*, certain Alariae, certain digitate Laminariae, Chorda, *Rhodymenia pertusa* (P. & R.), J. Agardh, and *Alaria fistulosa* (P. & R.).

In accordance with this division the northern and central Californian coast falls within the temperate region of algal distribution. Even to the nonbotanical observer the abundance of the brown seaweeds, the Phaeophyceae, is a striking feature of the rugged coast line of this portion of the State. Certain of these reach such a size and development that their utilization economically seems to be but a question of time and of information. In foreign countries, notably Japan and some portions of Europe, this group of plants furnishes a number of products of high commercial importance, used in the arts and sciences, as food, and as fertilizers.

The present report deals with the results of an examination of a portion of the central Californian coast, extending from San Francisco southward to the neighborhood of Point Sur, a distance of some 150 miles, and presenting a great variety of coast configuration,

No attempt has been made to study any other than those forms which from their size and abundance seemed to be best available for commercial use. Dry samples of all these have been submitted to the Bureau of Soils for chemical analysis, the results of which can best be interpreted by the experts of the department, and are hence not included in the present report.

The following is a list of the samples thus submitted:

*Macrocystis pyrifera* (Turner) Ag.  
*Nereocystis luetkeana* (Mert.) Post. & Rupr., stipe and pneumatocyst.  
*Nereocystis luetkeana* (Mert.) Post. & Rupr., Thallus.  
*Laminaria andersonii* Farlow.  
*Egregia menziesii* (Turner) Areschoug.  
*Postelsia palmaeformis* Ruprecht.  
*Fucus furcatus* Ag.  
*Fucus evanescens* Ag.  
*Dictyonereon californicum* Ruprecht.  
*Costaria turneri* Grev.  
*Gigartina radula* Ag.  
*Gigartina spinosa* Kütz.

All of these belong to the group of the brown algae, with the exception of the last two, which are members of the Rhodophyceae, or red algae.

Accompanying this report are submitted a number of maps based on the coast survey charts upon which have been plotted the position, extent, and nature of the kelp beds described in the following pages. These charts are the following:

1. Coast Survey Chart No. 5500, Point Pinos to Bodega Head.
2. Coast Survey Chart No. 5498, Monterey Bay, Cal.
3. Coast Survey Chart No. 5491, Monterey Harbor.
4. Coast Survey Chart No. 5476, Pfeiffer Point to Point Cypress.

In the following pages there will be given, first, a general description of the kelps examined with their ecological characters, and following this a survey of the coast with their distribution along it.

#### PHAEOPHYCEAE.

1. *Fucus evanescens* Agardh.
2. *Fucus furcatus* Agardh.

These are representatives of one of the most abundant genera of the brown algae, widely distributed in both the Atlantic and the Pacific Oceans. They are found between tide marks attached to the upper surfaces and the sides of rocks which are left bare at low tide. In many localities the alga is thus exposed for hours, living almost as much of the time out of water as in it. Each plant is attached by a small, irregular holdfast and its stem branches abundantly into a multitude of subdivisions, which flatten and dilate toward their tips, forming a dense cluster, which may reach a length of 2 or 3 feet, or even more under favorable circumstances. The flattened attachment disk is so closely adherent to the substratum that the stem will break before the holdfast gives way. At the flattened and broadened apices of the thallus may be found the conceptacles, or reproductive portions of the plant.

So far as is known all the species of *Fucus* are perennial plants and the reproductive activity does not seem to be dependent upon the season of the year, since mature oospheres and antherozoids escape at all times, and the young plants may be found growing in all

stages during the year. Just how fast the plant grows on this coast is not known. In a series of experiments commenced in August, 1911, definite areas of rocks, covered with a dense growth of *Fucus*, were entirely denuded of the plants. These will be visited at intervals, and the rate of growth may thus be determined. Such a study will, of course, require considerable time before any definite results can be recorded.

The individual plants are attached at irregular intervals apart upon the surface of the rocks on which they grow. The number of plants per square yard of surface area ranges from 15 to 33, with an average of 24.8 for 50 square yards examined. Ten such areas were selected at different points on the southern shore of Monterey Bay, and the total amount of *Fucus* from each was carefully weighed. The weights varied from 8 to 27 pounds, with an average weight of 18.5 pounds. These areas were taken at random in typical *Fucus* beds. At low tide, when the *Fucus* is exposed to the air, it lies in a mass covering the rocks so thickly that indirect handling only can determine the relative amount in any particular spot. All intentional selection of any more or less favorable spots was avoided in taking these areas, and they may be regarded as typical of the region. Most of the plants were in large, well-developed clusters, relatively few small plants being found. A number of other similar areas, some of much larger extent, gave approximately the same results as the 10 above cited and taken as typical. For example, one of them, measuring 3 by 25 feet,  $8\frac{1}{2}$  square yards in area, gave a weight of *Fucus* of 17.2 pounds per square yard. All of the above figures refer to damp kelp, drained free from sea water. To determine the loss of weight in drying, the kelp from five such areas was spread in the sun. After 26 hours' exposure, during which it had lost all feeling of dampness, it was collected and reweighed, with the following results:

Average weight:	Pounds.
Wet.....	17.8
Dry (44.3 per cent).....	7.9
Loss in weight (55.7 per cent).....	9.9

Thus the average loss of weight due to the evaporation of the water through 26 hours' exposure was 55.7 per cent of the total weight. This rough determination is of value only as indicating approximately the amount of water in the plant which could be removed by a simple drying in the process of harvesting. None of the salts contained in the plant effloresced upon the surface during this time. Evaporation to complete dryness would, of course, give a much higher per cent of water content.

### 3. *Egrecia menziesii* (Turner) Areschoug.

This species of *Egrecia* is one of the characteristic algae of the north temperate region of the Pacific coast. It ranges from Puget Sound southward to the neighborhood of Point Conception, its place from there southward being taken by another species of the same genus, *Egrecia laevigata*, Setchell.

Its large holdfasts are fastened to the rocks of the lower littoral and upper sublittoral zones, where it is never entirely uncovered by the receding tide. The rounded stem branches frequently, the branches terminating in long thick straplike leaves, about  $1\frac{1}{2}$  inches

in width, along the margins of which short lateral offshoots are crowded. These are of several sorts. The most are leaflike, with smooth uniform margins and surfaces. Others of similar form are irregularly ribbed and bear the reproductive organs. A third variety is long, filamentlike, and branched, while the fourth is modified into elongate ovoidal or ellipsoidal pneumatocysts, each usually bearing a small leaflike expansion at its apex. The total length of such a plant may reach 30 to 40 or more feet, though shorter ones are commoner. The ends of the long straplike thalli usually terminate abruptly, being frayed and worn through being lashed back and forth by the waves.

*Egregia* is abundant along the Californian coast among rocks beyond low-tide mark. It frequently accompanies the beds of *Macrocystis* and *Nereocystis*, replacing them in the shallower water near shore, along with species of *Alaria* of similar habit. What its duration of life may be is not known to me, as I have been unable to find any information on the subject. From having observed it at all seasons of the year at Pacific Grove, when collecting animal forms, I infer that it is perennial, or at least lives longer than a single year.

Individual plants of *Egregia* are usually more scattered than in the case of *Fucus* and are apt to be more intermingled with other forms. Ten square yards of rock surfaces covered with *Egregia* plants of average size were cleared, and the kelp carefully weighed. These areas were selected in the vicinity of Pacific Grove. The average weight of the damp kelp per square yard was 70.5 pounds. After 25 hours' drying in the open air 60.5 pounds of damp *Egregia* had lost 42.5 pounds, weighing but 18 pounds. This sample was not completely air dried, being somewhat damp to the touch.

The long tangled masses of *Egregia* make up a conspicuous part of the windrows of kelp washed up on the sandy beaches, especially during the fall and winter months after storms, when tons of kelp are thus rolled up.

Associated with *Egregia* are usually species of *Alaria*, a kelp of considerable size and frequently very abundant. Its holdfast is made up of a mass of rootlets or haptomeres, the stem is slightly flattened and bears two rows of basal leaves, the main stem ending in a long flat blade. It is likewise washed up on the beaches after storms, especially the distal bladelike portion, which breaks off and is renewed annually.

#### 4. *Costaria turneri* Greville.

Occurs on rocks below low-tide mark in the upper part of the sublittoral zone along with the foregoing species. It is attached by a rootlike holdfast, the stem is short and dilates into a broad leaflike thallus with three to five longitudinal undulating ribs which extend the whole length of the thallus. It occurs all along the coast from Point Conception northward to Puget Sound and Alaska. It is quite common at Point Pinos, Monterey Bay.

#### 5. *Dictyonereis californicum* Ruprecht.

Stem short, forking, the terminal thallus leaflike, ridged and folded in a netted pattern. It occurs sparingly in Puget Sound, but more abundantly southward, although it is always one of the

rarer algae. Associated with *Costaria*, *Alaria*, and *Laminaria* in semisheltered spaces between rocks beyond low-tide mark.

#### 6. *Laminaria andersonii* Farlow.

A strongly developed plant growing in the sublittoral zone upon rocks often exposed to strong surf. Its stem is rather short and almost woodlike, the thick blade of the thallus smooth and glossy, more or less split and digitate. The plant is perennial, the leaf being renewed each year. Members of this genus have been extensively used as a source of iodine and mannite, and as fertilizers in many countries.

Several species of *Laminaria* are found along the Californian coast, the one here cited being the most abundant in the region of Monterey Bay. It grows scattered and in groups and is frequently found fringing tidal channels where the currents run strongly back and forth, its strong elastic stem and firm thallus well adapting it for such a position.

#### 7. *Postelsia palmaeformis* Ruprecht.

Found on rocks on exposed points from the Strait of San Juan de Fuca southward nearly to Point Conception, Point Sur being given as about its southern limit. The treelike "sea palm" grows in small forests or groves at or near high-water mark in places where the waves dash the strongest. In this habitat it is often uncovered by the receding tide, but the dashing spray of the surf keeps it almost continually dripping. It is frequently found as a fringe along high-tide mark on precipitous cliffs, its strong elastic stem and leaves furnishing an almost perfect adaptation to the impact of the heaviest waves. During the winter months, however, it may be torn loose and cast up by the surf on sandy beaches as a part of the great masses of kelp thus heaped up.

The holdfast of *Postelsia* is strong and made up of a large number of rootlike processes or haptomerer arising from the base of the treelike trunk or stem. The latter is cylindrical, up to an inch and a half in diameter and tapering, 1 to 2 feet in height, and bears at its summit a crown of narrow, leaflike expansions. Each of these has a short basal stem, forking once or twice, the blade longitudinally ribbed and moderately thick. It is presumably perennial, but I have been unable to find any recorded observations upon this point.

A determination of the relative amounts of water and solid substance was made for *Postelsia* by means of drying completely in an electric oven. The following figures are typical of the results:

	Lot 1.	Lot 2.
Weight of damp fronds.....grams.....	400.00	200.00
Weight of dried fronds.....do.....	81.25	38.50
Loss in weight, or the amount of water.....do.....	318.75	161.50
Water in fronds.....per cent.....	79.69	80.75
Dry substance.....do.....	20.31	19.25
Weight of damp stems.....grams.....	400.00	
Weight of dried stems.....do.....	51.72	
Loss in weight, or water content.....do.....	348.28	
Water in stems.....per cent.....	87.04	
Dry substance in stems.....do.....	12.96	

8. *Nereocystis luetkeana* (Mertens) Postels and Ruprecht.

This species is the most striking and conspicuous of all the brown algae of the Pacific coast. It is attached by its enormous holdfasts to rocks in the sublittoral zone, and reaches its full development in from 10 to 12 fathoms of water. Its range is from the Shumagin Islands, Alaska, to the Santa Barbara Channel, Cal., and it is found floating in masses of several acres in extent in the Bering Sea up to the latitude of the Pribiloff Islands, according to Setchell and Gardner. All along the coast southward it is a common object floating in the water, and is an indication to sailors of their approach to land. Its favorite location appears to be in tidal channels where the currents are swift and strong.

Four regions may be distinguished in the adult plant, viz, the holdfast, the stipe or stem, the pneumatocyst or float, and the laminae or leaves. The plant is attached to the rocks by a huge holdfast, a foot or more in diameter, from which originates a long, slender stipe about one-fourth of an inch in diameter. Throughout the greater portion of its length the stipe is very slender; then, as it approaches the pneumatocyst, it increases gradually in diameter up to approximately three-fourths of an inch. A cavity now appears in its center and the whole stem dilates into the pneumatocyst, reaching a diameter of 6 inches or even more at the bulb. Just below the spherical bulb is a constriction, so that the cavity is given the shape of a straight retort. In the young plants the float is spherical, then, as maturity approaches, it becomes ovoid and finally elongated to a length of from 6 to 10 feet. The long tube thus formed is frequently made use of by the Alaskan Indians to siphon the water out of their boats, and the dried, tough, whiplike slender stipe was formerly used for fishing lines by the same people.

The laminae arise as two main expansions, each of which splits lengthwise repeatedly in growth, so that the result appears as two groups of leaves, borne on the distal end of the pneumatocyst. Each of these groups may have as many as 20 to 25 such leaves. Each lamina lengthens by a basally situated growth area, the activity of which makes up for the wearing away of the tips of the leaves by the waves.

*Nereocystis* reaches enormous dimensions under favorable circumstances. Specimens of 100 meters in length are recorded by Kjellman, of which some 80 meters form the stipe, 2 to 3 meters the pneumatocyst, and the remaining 17 meters the leaves. The leaves rarely reach 50 feet in length, one-half that being much more common. Along the Californian coast the extreme dimensions are very seldom reached, specimens 100 feet long being rare.

When the water is quiet the pneumatocysts float nearly upright in the water, appearing as round, gourdlike bodies at the surface, the leaves streaming off at one side from them. In tidal currents the floats lie lengthwise with the direction of the flow, and the long leaves stretch out beyond them beneath the surface. According to MacMillan the shifting of the great pneumatocysts when the tide changes is sufficient to overturn small skiffs which may be caught among them. Larger boats find a *Nereocystis* bed a safe anchorage if overtaken by a storm while off a lee shore, and Puget Sound fishermen often anchor their boats to a dozen of the pneumatocysts and



thus ride out a gale with no fear of being blown on the rocks. Similar use is made of the beds of *Nereocystis* and of *Macrocystis* along the Californian coast.

These gigantic plants are annuals, dying in the late autumn; their stipes break away above the holdfast, or occasionally the latter itself breaks loose, and the plants drift at the mercy of the waves, and are cast up in hundreds of tons along the beaches to decay and disappear. In the spring and early summer the young plants alone are to be found. Their growth must be rapid, for by midsummer the large plants are seen again. A great deal of the increase in length of the whole plant is of course due to the lengthening of the very slender stem.

I have been unable to find individual plants of *Nereocystis* in the region examined by me which attained anything like the maximum dimensions given by Kjellman, Mertens, Setchell and Gardner, and MacMillan. Specimens up to 100 feet in length are met with, of which length the leaves would make up 15 to 20 feet and the stipe and pneumatocyst the remainder. Those washed up on the beaches usually have the leaves badly frayed away, and often the stipe is broken as well. To pull loose from the rocks a vigorous adult plant, that is able to anchor a good-sized boat in a storm, is something of an undertaking, and the depth in which such a plant grows renders cutting it off at the base impossible. Consequently, the data which I have been able to secure as to the weight of the plants is rather unsatisfactory. The figures secured from the weighings of a number of good-sized average plants, however, range from 43 to 76 pounds in the damp condition. No comparative weighings were made of wet and dried material.

#### 9. *Macrocystis pyrifera* (Turner) Agardh.

This species of giant kelp makes up the bulk of the beds along the region examined. It grows on rocks off the coast in from 5 to 15 fathoms of water, generally, and ranges southward from Alaskan waters all along the coast. In this region it is especially plentiful in large beds near Santa Cruz and Monterey.

*Macrocystis* has the widest distribution of any plant known. In the Southern Hemisphere it encircles the globe, limited to the southward apparently by the circumpolar ice alone; it extends northward through all the South Temperate waters to the Tropic of Capricorn. It is recorded from the Strait of Magellan, Cape Horn, the Falkland Islands, South Georgia Islands, Tristan da Cunha, Cape of Good Hope, Prince Edward Island, Crozet Islands, Kerguelen, St. Paul, the west and south coasts of Australia, New Zealand, Chatham Island, Auckland Island, and in the Pacific Ocean, following the coast of the American continent up into the Northern Hemisphere to Alaska and the Bering Sea. In all these regions it reaches enormous extent. Dall (1875) records a patch 25 square miles in extent, northeast of St. George Island on a shoal in the open sea, and it is excessively abundant in the Aleutians. In the Southern Hemisphere it is much more extensive than this, if the tales of mariners be true.

The plant is attached to the bottom by a large holdfast, reaching 3 feet and more in diameter, and made up of a mass of hapteres. The stem at first branches equally, but later some of these divisions

grow much stronger than the others, attaining finally a length of from 200 to 300 meters. The primary growing point of each stem is located near the apex of the broad sickle-shaped or scimitar-shaped expansion at the tip. Successive parallel clefts appear in this vegetation point and progressively increase in length, the waves finally splitting the blade proximally into narrow segments, each one of which becomes a "leaf." The basal portion of each of these differentiates into a short stem with an oblong or pear-shaped pneumatocyst, the remainder becoming the broad and very long lamina. The upper surface of this lamina is corrugated irregularly, thus decidedly strengthening it. Its margin is dentate. This mode of leaf formation is really by means of a continual bifurcation of the growing point, one of the lobes thus formed growing more rapidly than the other and becoming the continuation of the stem, while the other develops a float and becomes a leaf. Thus, from one holdfast, a plant of enormous extent finally arises, its basally branched stems bearing uniserial leaves over 3 feet long, the whole trailing off through the water for hundreds of feet in a dense mass.

The mode of development of the young *Macrocystis* is well described by Skottsberg (1907). The young plant divides dichotomously; each part thus formed may develop into a stem. The further division of the terminal lamina is likewise dichotomous, but the outer segment rounds basally into a stem, while the inner one usually develops a float and becomes a leaf. The primary stem is very short in the young plant, and by the successive development of new circles of hapteres above the old ones the point of first branching becomes buried in the holdfast, making it appear that two, or indeed several, separate stems arose from the same holdfast. New stems therefore do not arise as outgrowths from the holdfast, but are formed only as branches of the original stem. During growth the internodal stems lengthen, reaching 2 to 3 feet, and exhibit a twisting, so that the leaves come to lie in different planes. In diameter the stems vary from one-fourth to nearly one-half an inch, and are extremely slender in comparison to the enormous extent of the whole plant.

The reproductive sporangia are borne on certain of the leaves, either basal ones or nearer the tip of the floating portion. But little is known of their structure or the early development of the plant.

The length of adult plants, as given by various authorities, varies from 30 to 1,500 feet. Hooker gives 100 to 200 feet as the ordinary length, but estimates others at from 300 to 700 feet. So far as I know none has been measured at Pacific Grove with a length of over 150 feet. Washed-up specimens are always broken or so hopelessly entangled in enormous masses that it is impossible to unsnarl them for the purpose of measurement.

Beds of these kelps many acres in extent, so dense that rowboats can scarcely be forced through them, are common all along the California coast. As the depth of water in which the plant grows is usually less than 100 feet, the greater portion of the plant is floating at or near the surface. By the first divisions of the young plant a considerable number of branches may arise, all of which become stems. The limit of growth of each of these stems would seem to depend upon its freedom from injury from waves and

storms. When attached to loose rocks the buoyancy developed by the increase in size of the plant often drags the holdfast, rock and all, free from the bottom, especially during storms, and the whole plant may be cast up on the shore or drift out over the ocean. The age of the plants and their period of life, if indeed they may be said to have anything resembling a stated period, is not known. As long as the growing point at the end of a stem remains vigorous, continuous growth of that stem would seem to be possible. In every bed of *Macrocystis*, however, broken stems and leaves, with frayed and torn ends, are found more or less decayed. The rate of growth of the tips of the stems seems to be also unknown. The leaves apparently rapidly reach their full growth and the older leaves along the stems are often tattered and broken, while sometimes the whole lamina has disappeared, leaving the floats alone, there being no regeneration of the leaf tissue. Such points as these would be of decided importance were this plant found to be of economic value. With a view to determine some of these a series of observations have been initiated upon a bed of *Macrocystis* not far from the Marine Biological Laboratory of Leland Stanford Junior University, at Pacific Grove, Cal. A large number of tips have been marked in order to determine the growth rate, but such observations must extend over at least a full year before they will have any weight. So far as I am aware no continuous observations have ever been made upon a given bed of kelp. In general the beds appear to maintain much the same position and location throughout the year, increasing somewhat in extent.

While I have never paid any attention to the life history of this plant before the present summer, I have for the past 19 years been more or less familiar with it, as it is the home of many forms of animal life which have been studied by myself or in the marine laboratory at Pacific Grove. During the years 1892 to 1894 an almost continuous bed of *Macrocystis* extended from Point Aulon to Almeja Point. This bed was from 50 to 150 feet in width and fully one-half mile long. Beyond Point Aulon to the northwest the kelp was much less abundant. During the summers of 1895 and 1896 I was absent from the laboratory and on my return in 1897 found that the first-named bed had entirely disappeared, nor has the area been again occupied by it save in two small patches. On the other hand, the bed off Aumento's Rock has increased enormously in extent and now forms the most conspicuous bed in the vicinity, being fully three-quarters of a mile long and up to 400 feet in width. I have no written record of the above, but believe it to be substantially correct, since I was collecting animal forms from these beds and from Aumento's Rock during the above summers and have done so at intervals since.

A plant fastened to the rocks in a depth of water up to 15 fathoms, branching freely in its lower portion well out of sight, associated closely with other individuals in the same kelp bed and extending off through the water for several scores of feet, presents almost insurmountable difficulties in an attempt to ascertain its weight or to estimate the amount contained in any given area of surface. One can neither be sure of collecting the whole plant nor of knowing what proportion of it he has, nor, finally, how many such plants enter into any given area. It is not difficult to cut off stems at from

15 to 20 feet below the surface of the water with a sickle attached to a long pole, but this is a long way from collecting a whole plant. I have collected and weighed many such branches and have found weights ranging from 37 to 92 pounds, the lengths varying from 50 to 100 feet. The time and facilities at my disposal have not enabled me to finish satisfactorily any such estimates. To get any accurate information as to the amount in any bed of *Macrocystis* I feel that an experimental harvest of a definite and considerable area is the only method which promises satisfactory results. In an area of kelp 100 feet long and 50 feet wide I counted 58 stems, but other areas showed a great range of variation from this.

The amount of stems and leaves showing at the surface is an indication in a general way of the density of a given bed, but with no information as to the extent of kelp below the surface, the extent of branching in the depths, or of how much may be considered a single plant. It thus becomes a very difficult problem to give any estimates which are anything beyond mere guesses. One has but to row out to a kelp bed and to look down through a water glass at the maze below for an hour or so to gain a vivid realization of its difficulty. Such an experimental harvest as I suggest could best be made with large boats such as the Chinese and Japanese fishermen use in the squid industry. At the time of my examination of the Monterey Bay beds all such fishermen were at work catching salmon, an employment so profitable that they could not be secured for any such work.

There are undoubtedly thousands of tons of kelp in the Californian beds of *Macrocystis*, but my data at present do not justify any estimate as to the probable yield per acre of surface.

#### RHODOPHYCEAE.

In addition to the above-described brown algæ there are a number of the red algæ which occur in abundance at various points and are of considerable bulk, such as the *Irideas* and *Gigartina*. *Gigartina radula* Ag. and *Gigartina spinosa* Kütz occur in abundance at Point Pinos, Monterey Bay, and in various other places in the lower littoral and upper sublittoral zones, along with the *Laminarias*. Their dark red thalli, roughened with short blunt processes from either surface, are conspicuous objects in almost every mass of kelp washed up on the beaches.

#### A RECONNOISSANCE OF THE PACIFIC SHORE LINE FROM SAN FRANCISCO TO POINT SUR.

In the following pages are given the results of a study of the occurrence of the kelps just described along 150 miles of central California coast. This stretch of shore line was examined at close range, and also with strong field glasses from high points of vantage when the conformation of the shore prevented close examination.

The coast line in question is quite varied in character, in part showing long stretches of sandy beaches; again rocky ledges and abundant tide pools or precipitous cliffs descending abruptly into the water. Accompanying this description are submitted sheets from Coast Survey Charts Nos. 5500, 5498, 5491, and 5476.

## GOLDEN GATE SHORE.

[Chart 5500. Sheet IV.]

Along the entrance to the Golden Gate from Fort Point to Point Lobos (Seal Rocks), a distance of 3 miles, the coast is precipitous and rocky, with but scanty algal growth, mainly *Fucus*. None of this is of sufficient extent to be of any commercial importance.

## POINT LOBOS TO SAN PEDRO POINT.

[Chart 5500. Sheet IV.]

From Point Lobos, or Seal Rocks, to the cove just north of San Pedro Point, a distance of 13.7 miles, a straight sandy beach stretches continuously. Behind its upper third are sand dunes, while the remainder is in front of high vertical cliffs, reaching an elevation of 400 to 500 feet near Mussel Rock. No kelp whatever is found along this beach save at its lower end, where scattered *Fucus* grows at Mussel Rock and on the small rocky headlands forming the north boundary of San Pedro Cove. The precipitous sides of Montana Mountain here reach the sea and form San Pedro Point, with cliffs 500 to 1,000 feet in height. On the south side of the cove is located the first considerable bed of kelp. It is composed of *Egregia*, succeeded by *Nereocystis* toward the point. This bed of *Egregia* is about 350 feet in length by 50 to 75 feet in width. The bed of *Nereocystis* is estimated at 300 feet in length by 125 feet in width. Careful counting of the floats gave 5,000 as a total number of plants for this bed. According to the statements of the station agent at Tobin, a station on the Ocean Shore Railroad on the cliff overlooking the kelp bed, hundreds of tons of kelp are washed ashore on the San Pedro Beach every winter. If we take 50 pounds as the average weight of a *Nereocystis* plant—and this is well within the average—the total weight of the 5,000 plants would be 250,000 pounds, or 125 tons, which is probably not far from correct. For the *Egregia* bed of 1,944 square yards the average of 70 pounds per square yard would give 136,080 pounds, or 68 tons. On the south side of San Pedro Point is another *Nereocystis* bed nearly as large as the one just described. It is estimated as containing some 4,000 plants and would furnish 100 tons of kelp on the same basis. All three beds would furnish nearly 300 tons of kelp and, so far as the *Nereocystis* is concerned, would be an annual crop. San Pedro Valley has many vegetable ranches supplying the city trade. It would seem that here at their doors is a large amount of valuable fertilizer going to waste which might be harvested and utilized at but little expense.

## SAN PEDRO POINT TO PILLAR POINT.

[Chart 5500. Sheet IV.]

The first third of this total distance of 11.8 miles is a sheer cliff, with but little opportunity to reach the water's edge. A narrow fringe of *Postelsia* occurs at intervals and becomes much more abundant at Point Montara. Here for a distance of nearly 2 miles *Postelsia* is quite common, *Fucus* less so, and *Nereocystis*, *Egregia*, and *Macrocystis* at intervals. From Montara Point to Pillar Point a series of

parallel reefs jut obliquely out from the narrow sand beach in a northwesterly direction, being outcrops of the greatly tilted strata. Between these reefs the kelp flourishes, and upon their outer exposed ends *Postelsia* finds a footing. Along the sand beach considerable red algae is also continually washed up. This region could supply a limited amount of fertilizer to the ranches in the neighborhood.

**PILLAR POINT TO PESCADERO CREEK.**

[Chart 5500. Sheets IV and V.]

This distance of 18.25 miles comprises the region of Half Moon Bay and the nearly straight sand beach beyond. The bluffs are at first low and then increase in height to from 200 to 300 feet.

Off Pillar Point and extending southerly across the northern portion of Half Moon Bay is a large bed of *Macrocystis* of irregular form. This was studied from the 150-foot high point with a strong field glass, as I was unable to procure a boat. The main bed is somewhat crescentic in form, is fully one-half mile long and from 100 to 200 feet in width. Other more scattered beds occur in the region, which together would total up as much as the large bed. *Nereocystis* and *Egrecia* are also abundant, but *Macrocystis* is predominant. This bed forms the principal source of the kelp which is washed up along the shore of Half Moon Bay in great quantities during the winter months. Some 6 to 12 acres are included in the main bed, which occupies a depth of from 12 to 14 fathoms according to the chart soundings. Aside from this bed no considerable masses of kelp are found for some distance. Near Point Miramontes occur a few ledges with *Postelsia*, and, opposite Purissima, a small cove some 1,000 feet across is filled with rocky ledges, between which considerable *Egrecia* is growing and outside of it a small bed of *Nereocystis* containing about 500 large plants. Similar beds are found at intervals, though in no great amounts. Within a mile there are probably 2,000 or 2,500 *Nereocystis* plants, considerable *Egrecia*, and scattered *Macrocystis*, with *Postelsia* on most ledges.

In this region the ranches near by could secure a good deal of valuable fertilizer with no great difficulty. There is not enough, however, to meet any great demand.

**PESCADERO CREEK TO ANO NUEVO POINT, 14.7 MILES.**

[Chart 5500. Sheet V.]

Below the mouth of Pescadero Creek the shore becomes rocky for some 4 miles, and scattered clumps of *Fucus*, *Egrecia*, and *Postelsia* are found. Near Pigeon Point the same characteristics occur again, followed by a sandy beach, broken only by Franklin Point before Ano Nuevo Point is reached. At Franklin Point scanty shore kelps are found, but no large beds until Point Ano Nuevo is reached.

**ANO NUEVO POINT TO SANTA CRUZ LIGHT, 21 MILES.**

[Chart 5500. Sheet V.]

South of Ano Nuevo Point, *Macrocystis* becomes abundant and the first large beds of this kelp occur. The first of these is immediately south of the point and extends in a direction parallel with the coast, in a dense bed, for some 4 miles in length and varying in width from 200 to 600 feet. This bed is nearly continuous until off

Greyhound Rock, where it becomes narrower and more interrupted. Three of the four miles at least are occupied by kelp, and a conservative estimate would place the area of this bed at from 150 to 200 acres.

From Greyhound Rock on down the coast to El Jarro Point, 4 miles, the *Macrocytis* beds are more scattered and are narrower, ranging from 30 to 50 feet in width. The same condition continues farther southward, save that larger beds become more numerous. Between Sandhill Bluff and Table Rock a large bed, 300 feet wide and nearly a mile in length, occurs. A similar widening occurs beyond Needle Rock, with narrower beds connecting these areas. At Terrace Point the Santa Cruz beds proper may be said to begin. These beds range from 100 to 500 feet in width and extend parallel to the shore line, at a distance of from 500 to 1,000 feet from it, in unbroken series nearly to Point Santa Cruz. Inside of this outer zone of *Macrocytis* occur scattered *Egrecia* masses, rising to the surface, but not making continuous beds. A summary of the estimated area of these beds is the following:

	Acres.
Ano Nuevo bed, 4 miles-----	150 to 200
Greyhound Rock to Sandhill Bluff, $8\frac{1}{2}$ miles-----	19 to 47
Sandhill Bluff to Terrace Point, $5\frac{1}{2}$ miles-----	60 to 120
Terrace Point to Santa Cruz Point, 2 miles-----	24 to 120
Total acreage-----	253 to 487

From 250 to 500 acres of *Macrocytis* are present along a coast distance of 21 miles. As these are all conservative figures, the larger figure is probably nearer the correct amount than the smaller one.

#### SANTA CRUZ HARBOR TO MONTEREY HARBOR.

[Chart 5498. Sheets V and VI.]

From Santa Cruz to Monterey a long sweep of sand beach extends for a distance of 38 miles, broken only near Santa Cruz by any rock formations. This stretch is destitute of kelp save in the neighborhood of Capitola, where two large beds of *Macrocytis* are found. Each of these is accompanied by some *Egrecia* on its inner border. At the left of the Capitola Wharf is a large and dense bed, three quarters of a mile in length and averaging 300 feet in width. On the right of the wharf a similar bed extends around Soquel Point, lessens gradually in amount, and disappears before reaching Santa Cruz Harbor. This bed is  $3\frac{1}{2}$  miles long and averages 500 feet in width for most of its extent, and contains an area of approximately 200 acres. The smaller bed on the left of the wharf is estimated at 30 acres, the two together giving a total of 230 acres. Thus within a radius of 20 miles of Santa Cruz there are growing between 600 and 700 acres of *Macrocytis*. If this kelp proves to be of any agricultural value as a fertilizer, this region will be of great importance, at least locally. The great fruit-producing section back of the Bay of Monterey should welcome any such addition to its resources.

#### MONTEREY HARBOR TO POINT LOBOS.

[Charts 5498 and 5476. Sheets VI and VII.]

As before stated the remainder of the coast line from Santa Cruz to Monterey is destitute of kelp, the shifting nature of the long sandy

beach affording no foothold for the algae. Beginning at Monterey, however, and extending around the peninsula to Carmel Bay follows a stretch of coast which shows a great variety and abundance of the brown algae. The shore line is in the main rocky, interrupted only by a few sandy beaches, and has a continuous fringe of *Fucus* throughout nearly its whole extent. The amount varies with the inclination of the bottom and the consequent width of the tidal zone. In a few places, notably near Point Pinos, this reaches a width of 100 to 200 feet, and the rocks are thickly covered with *Fucus* and other brown algae. At Point Pinos the larger *Phaeophyceae*, such as *Laminaria*, *Alaria*, *Egregia*, *Nereocystis*, *Costaria*, *Dictyonuron*, *Postelsia*, and many others, are common. From Almeja, or Mussel Point (locally "Chinatown Point"), a distance of  $2\frac{1}{2}$  miles, I would estimate the average width of the *Fucus* zone at 10 feet. Applying the average weight of *Fucus*, 18.5 pounds per square yard, as given on page 196 of this report, we have a total of 294,335 pounds, or 147 tons, of this plant. As at least 60 per cent of this weight is water, about 50 tons would represent the amount of solid substance represented in  $2\frac{1}{2}$  miles.

The other *Phaeophyceae* mentioned as occurring here do not form large continuous beds of any great extent, but grow wherever they can find a foothold and suitable environment. They should be reckoned with, however, as forming a substantial part of the kelp resources of this region.

At Point Aulon occurs the first considerable bed of *Macrocystis* on the south side of Monterey Bay, though scattered masses of it are found in Monterey Harbor and at intervals along the coast to this point. This bed is about three-fourths of a mile in total length and would probably amount to between 5 and 8 acres in extent, though its irregularity makes an estimate somewhat difficult.

On the ocean side of Point Pinos and on down the coast to Carmel Bay the larger brown algae predominate as the coast becomes more rugged. *Postelsia* is found occasionally on the rocks, but not abundantly at any place. *Macrocystis* and *Nereocystis* are found scattered along at intervals, but in beds of no great extent, though the total is probably large.

In Carmel Bay scattered beds of *Macrocystis* are common, though none of very large extent. *Fucus* occurs at intervals between tide marks and *Egregia* beyond.

#### POINT LOBOS TO POINT SUR.

[Chart 5476. Sheets VII and VIII.]

At Point Lobos the coast becomes more rugged, with precipitous cliffs descending into the water. This character develops rapidly as one goes down the coast toward Point Sur. The cliffs become sheer perpendicular walls with the waves beating against their bases, and but scanty foothold is given for algal attachment. *Postelsia* clings wherever it can, and in the tideways between the points and detached rocky islets *Nereocystis* grows in no great numbers. The most of the shore line here can be reached only by boats, and boats are few and far between.

In the course of the present inquiry I have been no farther south than Kaslers Point, but in previous summers I have been on collect-



ing trips as far down the coast as the mouth of the Big Sur River, some 20 miles below Point Lobos, and have collected at all available points which could be reached along the shore. From these former trips and from information from others I have learned that the first considerable beds of *Macrocystis* lie below Point Sur, approximately as indicated on the Coast Survey charts of this region. These beds are scattered over some 5 miles of coast between Point Sur and Cooper Point, and are very extensive. Upon the accompanying chart I have accentuated the position of these beds as given by the Coast Survey, but can not give any estimate of their area, as I have not seen them recently. The conventional signs on the chart indicate the presence of kelp, but give no information as to its extent save in a very general way. The beds are probably as great, if not greater, than those in the neighborhood of Santa Cruz. Various persons have told me on inquiry that they contained "hundreds of acres," but I, of course, place no great weight upon such estimates. These beds form a haven of refuge for small boats when caught out in a storm. They are composed mainly of *Macrocystis*, though *Nereocystis* occurs frequently. Along the shore rocks a little *Fucus* is found occasionally, and *Egregia* and other large species at intervals. As Point Sur is near the southern limit for *Postelsia*, this plant becomes rare.

#### SUMMARY.

Summing up the results of this examination, it would appear that for this region the marine algæ which are most favorable in point of abundance and location for purposes of commercial use as fertilizers are the giant kelps *Macrocystis* and *Nereocystis*, together with the more common shore forms *Fucus* and *Egregia*, with the local addition of several other brown and a few red forms. If these kelps are shown by analysis to contain the necessary constituents to make them of value, the region near Santa Cruz offers the largest supply. All along the coast local needs can in part be filled by the kelp which is washed up on the beaches during the winter storms, and by harvesting from boats. The greatest factor in determining the permanent value of these beds will manifestly lie in the rapidity of their reformation, or reforesting after such a harvest. For *Nereocystis* the facts are known, as it is an annual plant, and if taken in the fall and winter months should furnish a continuous annual supply in such places as San Pedro Cove. Unfortunately it does not grow in this region in the abundance which it manifests in northern waters. Concerning *Macrocystis*, we know nothing as to the rapidity of its growth, nor as to the length of life of the individual plant, and the same lack is evident with respect to most of our algal forms. These data must be secured through further studies continued through a longer space of time than was available for the present report.

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# APPENDIX N.

## THE KELPS OF THE SOUTHERN CALIFORNIAN COAST.

During the summer of 1911 the extent, locations, and botanical and ecological characteristics of the kelp between San Diego and Point Conception were investigated. Interviews were also held with those parties in the neighborhood who are studying or attempting to utilize the kelp as a source of potash for fertilizer.

For the purposes of making the investigations the Marine Biological Association of San Diego allowed the use of the *Alexander Agassiz*, an 85-foot, ketch-rigged, 60-horsepower, auxiliary gasoline launch. This ketch is especially outfitted for scientific oceanic work and is used several months a year in research work. To the usual equipment was added a pair of scales, 50 drying trays, and kelp cutters.

The cruise was begun from San Diego. We proceeded along the coast from one-half to 1 mile offshore to Point Conception; then, after returning to Santa Barbara for supplies, we steamed around Anacapa, Santa Cruz, Santa Rosa, San Miguel, San Nicolas, Santa Barbara, Catalina, and San Clemente Islands. In this way all the kelp beds known from San Diego to Point Conception were seen and estimated. The total length of the trip was 730 miles. The estimated area of the beds is given in Table I and is shown as observed on the charts accompanying this report. The beds in some parts of the Santa Barbara Channel and around the islands were very difficult to estimate on account of the strong currents running, thus causing the kelp to run under the water. The areas were obtained by means of planimeter and compasses and in small areas by estimate.

Table I indicates area in square miles of kelp between Point Conception and San Diego, as shown on charts 5100 and 5200 of the Coast and Geodetic Survey.

TABLE I.  
CHART NO. 5100.

Sheet No.	Kelp bed No.	Character.	Area square nautical miles.	Sheet No.	Kelp bed No.	Character.	Area square nautical miles.
			<i>Sq. miles.</i>				<i>Sq. miles.</i>
Sheet 18.....	1	V. H.	5.40	Sheet 17.....	18	M.	0.23
	2	V. H.	2.30		19	M.	.24
Sheet 17.....	3	M.	.24		20	M.	.22
	4	M.	.97	Sheets 14, 15, and 16.	21	M.	.76
	5	M.	.25		22	T.	.10
	6	M.	.14		23	T.	.07
	7	M.	.25		24	M.	1.60
	8	T.	.37		25	M.	.13
	9	T.	.08		26	T.	.13
	10	T.	.26		27	H.	2.19
	11	T.	.06		28	H.	.44
	12	T.	.11		29	H.	1.80
	13	T.	.13		30	H.	.12
	14	T.	.06		31	H.	.43
	15	T.	.36				
	16	T.	.06				
	17	M.	.24	Total.....			{ 19.82 22.82

<sup>1</sup> Nautical miles.

<sup>2</sup> Statute miles.

TABLE I—Continued.

CHART NO. 5200.

Sheet No.	Kelp bed No.	Character.	Area square nautical miles.	Sheet No.	Kelp bed No.	Character.	Area square nautical miles.
			<i>Sq. miles.</i>				<i>Sq. miles.</i>
Sheet 13.....	1	V. T.	0.28	Sheets 9, 10, 11, and 12.	20	M.	1.93
	2	T.	.01		21	T.	.40
	3	T.	.006		22	T.	.12
	4	T.	.004		23	T.	.60
	5	T.	.006		24	V. T.	.12
	6	T.	1.00		25	M.	9.26
	7	T.	.11		26	V. T.	.26
Sheets 9, 10, 11, and 12.	8	H.	1.10	Sheet 13.....	26	T.	.51
	9	M.	1.22		27	M.	.76
	10	T.	2.20		28	H.	.26
	11	M.	3.90		29	H.	2.21
	12	M.	2.90		30	V. H.	1.75
	13	M.	2.55		31	V. H.	8.00
	14	M.	.65		32	M.	.62
	15	M.	6.15		33	M.	.91
	16	T.	1.00		34	M.	2.04
	17	T.	.52				
	18	T.	.26				
	19	T.	1.31				
				Total.....			<sup>1</sup> 54.085 <sup>2</sup> 62.26

<sup>1</sup> Nautical miles.<sup>2</sup> Statute miles.

## GRAND TOTAL.

Chart No.	Square miles.	
	Nautical.	Statute.
5100.....	19.82	22.82
5200.....	54.085	62.26
	73.905	85.08

## SUMMARY.

Very heavy beds (V. H.).....	17.45	20.01
Heavy beds (H.).....	8.54	9.83
Medium beds (M.).....	37.04	43.35
Thin beds (T.).....	9.625	11.03
Very thin beds (V. T.).....	.65	.77
Total.....	73.905	84.99

Harbors accessible to the "very heavy beds" are San Diego Bay; Corral Harbor, San Nicolas; Bechers Bay, Santa Rosa; and Cuylers Harbor, San Miguel.

Harbors accessible to "heavy kelp beds" are Smugglers Cove and Northwest Harbor, San Clemente; Bechers Bay and Johnsons Lee, Santa Rosa.

Harbors accessible to "medium kelp beds" are mainland from Encinitas to Coxo Anchorage and Bechers Bay, Santa Rosa.

Additional kelp beds are to be found along the Mexican coast off the Coronado Islands, Todas Santos Island, Banda Point, Santa Tomas Point, San Jose Point, San Jacinto Point, Geronimo Island in Rosario Bay, Cedros Island, and other points farther south. According to local fishermen these beds extend to Magdalena Bay. The author has seen the beds as far south as Cedros Island. Many of the beds are heavy. These beds, however, all lie within the marine league of the Mexican coast.

On the trip samples of kelp were taken from the larger kelp beds, and these samples were dried on trays until they were of a leathery consistency; then stored in glass jars, and finally shipped in soil sacks to the laboratories of the Bureau of Soils at Washington, D. C. Specimens taken from various parts of the beds were weighed and dried whole.

The kinds of kelp found were the *Macrocystis pyrifera* and *Pelagophycus porra*. Of these the *Macrocystis* forms the principal beds and is found abundantly over the area, while the *Pelagophycus* is only sparsely distributed over limited areas.

The *Macrocystis pyrifera*, or "devil's apron," is a perennial kelp which locally reaches a length of about 100 feet. It consists of many stems growing from a root stock or holdfast which is attached to a stone at a depth of, usually, from 4 to 10 fathoms. The individual stems carry serrated edged leaves radiating from them. Each of the upper leaves has at its base a pear-shaped bladder which acts as a float. At the proximal end of the stem occur bladderless leaves upon which are produced the sori; the spores drop and form new plants.

From casual observation and hearsay, when the top portion is cut off the plant will regenerate in about 60 days; but new plants may take more than a year for the reestablishing of a bed, due to their spores forming in the autumn.

The *Macrocystis* was found in beds off the rocky portions of the coast in depths between 4 and 12 fathoms, the greater portion being in not more than 10 fathoms. The shallowest depth found was 2½ fathoms in Johnsons Lee, Santa Rosa Island. The heaviest beds were found on the windward side of the more exposed islands, San Miguel, San Nicolas, and San Clemente; also off Point Loma on the mainland. Much thinner beds were found off Santa Barbara Island, Santa Cruz, Anacapa, and along the mainland from Encinitas to Coxo Landing. Catalina was the only island practically devoid of kelp, there being only some very small patches on the windward side. In Tables I and II the heaviness of the beds is marked by means of the following scale:

- V. H. Very heavy: Matted and compact.
- H. Heavy: Compact.
- M. Medium: Individual plants.
- T. Thin: Plants distinct and well separated.
- V. T. Very thin: Plants scattered.

Colors are used in the maps to indicate the same thing.

Peculiar specimens of *Macrocystis pyrifera* were found off Anacapa Island and at Johnson's Lee, Santa Rosa Island. In these the bulbs were spherical instead of being pear shaped. However, these occurred on plants with the pear-shaped bulbs, and would thus seem to be aberrant forms.

The *Pelagophycus porra* or "elk kelp" is very limited in its distribution. It always occurs in deeper water than the *Macrocystis pyrifera* and is distinctly separated from it. The elk kelp is found in water 12 to 18 fathoms in depth; it consists of a holdfast, securing it to a rock; a long slender stem from 72 to 90 feet long; an enlarged body, 6 to 8 feet long; a bulb, 6 to 8 inches in diameter, and two prongs, 5 to 8 feet long, on which are carried leaves 15 to 18 inches

in width and 12 to 14 feet long. The plant is an annual and reproduces by means of spores formed in sori on the large leaves.

Contrary to general report, no *Nereocystis gigantea* or Ribbon kelp was found growing south of Point Conception. Specimens found on the shore have probably been drift specimens from north of the point.

TABLE II.—*Dimensions and weights of various samples of kelp.*

MACROCYSTIS PYRIFERA.	
Weight:	
1 cubic yard—	
47 pounds, Point Loma Station.....	1
26 pounds, La Jolla Station.....	3
Weight:	
1 plant—	
50 pounds, Santa Barbara Station.....	9a
81 pounds, Santa Barbara Station.....	9
PELAGOPHYCUS PORRA.	
Weight:	
1 plant—	
42 pounds, Point Vincente, length, 96 feet.	
30 pounds, San Nicolas, length, 87 feet.	
The stations where samples were taken, together with soundings, are shown on the accompanying maps, also in Table III.	
The estimated quantity of kelp in the entire area, assuming 30 pounds per cubic yard as a conservative estimate of the average weight, and allowing 93 per cent for evaporation, would be:	
Square yards in 1 statute mile.....	3, 097, 000
Number of square miles.....	85
Square yards.....	263, 296, 000
Cutting 1 fathom deep.....	2
Cubic yards.....	526, 592, 000
Pounds per cubic yard.....	30
Wet plant, pounds.....	15, 797, 760, 000
7 per cent for ash, pounds.....	1, 105, 843, 200
Divided by 2,000 (tons of ash).....	552, 921

The ash, which is nearly all potassium chloride, is about 7 per cent of the wet weight, whereas the air-dried kelp is from 15 to 20 per cent of the wet plant. The air-dried kelp contains about 25 per cent potassium salts.

TABLE III.—*Stations where samples of kelp were collected.*

No.	Location.	Latitude.	Longitude.
		° ' "	° ' "
1.....	Point Loma Lighthouse.....	32 39 30	117 16 00
2.....	Bird Rock.....	32 45 06	117 17 00
3.....	La Jolla.....	32 51 30	117 16 06
4.....	Encinitas.....	32 27 00	117 43 06
5.....	Point Firman.....	32 43 12	118 21 30
6.....	Malaga Cove.....	32 48 36	118 24 26
7.....	Point Las Pitas.....	34 19 30	119 15 00
8.....	Summer Land.....	34 24 15	119 35 45
9.....	Santa Barbara, outside edge.....	34 24 00	119 40 36
9a.....	Santa Barbara, inside edge.....	34 24 00	119 40 36
10.....	Naples.....	34 25 12	119 54 45
11.....	Fort Canyada (Quemada).....	34 27 24	120 07 00
12.....	Little Coyo.....	34 25 15	120 24 30
13.....	Anacapa.....	34 00 55	119 23 22
14.....	Gull Islands.....	33 54 30	119 49 15
15.....	Anglers Cove.....	34 03 10	120 21 00
16.....	Tylers Bight.....	34 00 33	120 24 15
16a.....	Johnsons Lee.....	33 53 45	126 00 00
17.....	San Nicolas.....	33 16 50	119 37 45
18.....	Santa Barbara Island.....	33 28 06	119 01 06
19.....	San Clemente.....	32 57 09	118 35 12
20.....	Smugglers Cove (Clemente).....	32 48 12	118 23 00

The local kelps have been analyzed by Mr. Balch, of Coronado. These analyses appear in a bulletin on "The chemistry of certain algae of the Pacific coast," *Journal of Industrial and Engineering Chemistry*, vol. 1, No. 2, December, 1909.

There is at San Diego a company with a process already developed for which they have patents pending in this and other countries, whereby they claim to have solved the best method for producing potassium chloride and other by-products. They have a 6,000-ton-a-year plant ready for operation at Encinitas, and a 50-foot launch for cutting the kelp. This boat is not entirely successful at present, owing to the method of operation and lightness of gears. The cutting is by means of two 10-foot knives at a depth of one fathom below the surface, placed on opposite sides of the boat. After cutting, the kelp will be allowed to drift ashore.

Problems that may affect the cutting of kelp are:

1. The value of kelp beds as breakwaters for the coast line. This may be an important consideration near some of the harbors, such as San Diego and Santa Barbara.

2. The fish that may use the beds as a refuge.

3. The effect upon the food supply of these fish.

4. The value of the beds as spawning grounds for many oceanic forms.

However, the exposed channel islands could be used without harm to anyone, and as some of the large beds of kelp are located near them and as they have plenty of fresh water, work might be carried on on them successfully.

W. C. CRANDALL,

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and Captain of the Station Boat, Special Agent United  
States Department of Agriculture.*

APPENDIX O. *included*

**BRIEF NOTES ON THE KELPS OF ALASKA.**

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During the investigations upon which the *Albatross* was engaged during the months of June, July, and August, 1911, there was small opportunity to make observations regarding the abundance of kelp.

In bad, foggy weather the ship would anchor in some sheltered bay until it cleared up. There opportunities were taken to examine the kelp. Whenever possible, specimens were collected and dried.

North and west of Sitka kelp is not found growing abundantly. In some bays examined no kelp at all could be found. In others only two or three species. From Sitka southward the channels among the many islands along this part of the coast are more abundantly supplied with kelp. On the trip northward no note was taken of the abundance or species, and on the trip southward the vicinity of Sitka was the only one examined.

Rockweed and eelgrass are included in these observations. Rockweed grows along the beach between the high and low tide levels and is found growing most luxuriantly on a rocky shore. Eelgrass grows just below the low-tide level in sheltered bays. The large species of kelp are found in deeper water.

Dulse. *Rhodymenia palmata linearis*. Specimen No. 1.

Along the beach near the Indian mission of Yakutat, Yakutat Bay, five Indians were engaged in sacking dulse which had been spread out to dry. In frosty weather it is washed upon the beach in sufficient quantities for a man or woman to gather two or three sacks of it in an hour. The Indians are very painstaking in gathering up every leaf, no matter how small, but as the dried leaves are worth \$3 per sack, and three sacks of the fresh plants make one of the dry, this care is only natural. After a storm an unusual amount of dulse is washed upon the beach, and the Indians gather and clean it, after which they dry it by spreading it out thinly along a gravelly beach, or hang it over poles. When dried, dulse is not brittle, but rather rubbery. I found that I could chew it almost as easily as I could a rubber band. It is used as an article of diet by the Indians as well as by many white men. It is prepared by boiling and is served with seal or herring oil, and the Indians are very fond of it. It is also used as a medicine.

At Sitka, Baranof Island, three different Indian huts were seen, which had from two to four long poles each, covered with drying dulse. The growing plants could not be located at Yakutat or at Sitka.

*Nereocystis luetkeana* P. & R.

The head of Resurrection Bay, at Seward, was examined for kelp, but we were unable to find any of this species. Upon leaving the bay many single stalks were seen floating on the water. It was always seen floating singly, never in bunches. Three or four stalks will float for days within a few feet of each other, but never join together.

At Sunday Bay a large patch was found growing off a rocky point which was exposed to the full force of the waves. One specimen was pulled into the boat and measured. The length of the piece was 50 feet and it broke off about 5 feet from the end. The laminae measured 10 to 15 feet. At this place the water was from 10 to 60 feet in depth.

No specimens were seen near MacLeod or Zaikof Bays, Montague Island, Prince William Sound. At the following localities dead specimens were noted floating: Sitka, Baranof Island, Biorka Island, Cape Scott, and Union Bay, Vancouver Island, and at Seattle, Wash.

*N. luetkeana* is found from Puget Sound to the Shumagin Islands. It grows in exposed places and only once in a while is any found in a protected spot. (Proc. Wash. Ac. Sci., 111, 1901, p. 431.)

*Macrocystis pyrifera* Ag. Specimen No. 7.

Sheltered by the islands near Sitka, Baranof Island, many small patches of *M. pyrifera* were found. This species was not seen north of Sitka. At Biorka Island large patches grow along the eastern side of the island. This is the sheltered side. Symonds Bay was examined and the western or sheltered side was full of this species. *M. pyrifera* in these localities was growing in from 10 to 20 feet of water.

*Alaria lanceolata*. Specimen No. 9.

At Sitka this species was found growing thickly over the rocks just below the low-tide level. The islands nearly sheltered the places where the species was growing. The water was from 2 feet in depth to as deep as I could see.

*Alaria lanceolata*. (?) Specimen No. 6.

At Symonds Bay, Biorka Island, this species of *Alaria* grew abundantly along the sheltered side of the bay, in water from 4 to 10 feet deep.

*Alaria* sp. (?)

Along the most exposed parts of Sunday Bay a species of *Alaria* was found. Upon pulling in a stalk of it I found that it broke off 7 or 8 feet below the surface of the water. There was a long central stem with a continuous leaf on each side of it. The stalk was 6 to 8 inches in width. Depth of water, 10 to 20 feet. It was found growing with *N. priapus* and was not found in sheltered places.

*Holosaccion glandiformis*. Specimen No. 10.*Cryptophyllum geminatum*. Specimen No. 8.

At Sitka, Baranof Island, a large floating specimen of this species was seen. Along the sheltered eastern side of Biorka Island many single plants were growing in 5 to 8 feet of water.



*Specimen No. 11.*—This specimen was picked up along the beach at Sitka.

*Specimens Nos. 4 and 5.*—These two small species were found growing on the beach of Japonski Island. No. 4 has leaves with rough surfaces, while the leaves of No. 5 are smooth on the surfaces. These species attain a height of 2 to 3 inches.

*Fucus evanescens macrocephala* Kjellm. Specimen No. 2.

*Fucus evanescens* Ag. forma, Kjellm. Specimen No. 3.

These species of rockweed are found in all the localities examined. They grow between the high and low tide levels and sometimes plants are found almost out of reach of the water. Specimens Nos. 2, 3, and 10 were collected at Sitka.

#### EELGRASS.

The head of MacLeod Bay, Montague Island, is covered with eelgrass. It grows in 3 or 4 feet of water and is one of the best spawning grounds for herring.

EDWARD C. JOHNSTON,  
*Fishery Expert, U. S. S. Albatross.*

## APPENDIX P.

### THE COMPOSITION OF KELPS.

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#### METHODS OF ANALYSIS.

*Preparation of sample.*—The specimens received from Capt. Crandall (San Diego groves) were mostly large pieces of the plants, dried until efflorescence had begun and then stuffed into sample sacks. Further drying took place in transit and in the laboratory, so that when they were removed from the sacks they were in the form of hard balls or "wads," covered with their salts. It was difficult to disintegrate the tough, hard masses, and where that was attempted the salts fell off and had to be distributed between the portions as justly as was possible by guess. It was considered more desirable, therefore, to take entire balls of the material as samples. The only objection to this procedure was the large size of the sample obtained. The specimens received from Prof. Rigg (Puget Sound groves) were cut up into coarse pieces, and those from Prof. McFarland (Monterey groves) into fine pieces, so that samples of small size were easily possible. Where effloresced salts had formed, these had generally collected in the bottom of the containers. An effort was made invariably to distribute the salts uniformly through the entire lot.

The samples then chosen were placed on watch glasses or aluminum trays and were dried at a temperature of 103° C. for varying lengths of time, always exceeding 7 hours. They were then ground in an iron mortar. If hard and woody, they were ground finally to a condition of extreme pulverulence in a ball mill, while if thin and papery they were ground to the desired degree of fineness in the mortar—to pass a sieve of 16 apertures per linear inch.

*Determination of potash, soluble salts, and ash; incidentally organic matter.*—Samples, 0.5 gram, or thereabouts, in weight, weighed directly in tared platinum crucibles, were placed upon an asbestos-covered gauze, over a flame; the temperature of the gauze in its center was that of dull redness. At the temperature resulting in the crucibles the kelp began to distill and to evolve gases of a combustible nature which were ignited. On the disappearance of the flame at the mouth of the crucibles the samples were thoroughly stirred with a glass rod, and were heated further until all tarry matter was completely driven off. A loose black or gray powder of charcoal resulted. This was transferred completely to a 200 cubic centimeter beaker, containing 25 to 50 cubic centimeters of water, and was boiled vigorously, covered the while with a beaker cover, until the volume had been reduced to less than 25 cubic centimeters. The

resulting solution was filtered free of solid matter, the filtrate being caught in a platinum dish. The filter was washed thoroughly with hot water.

To the filtrate was added a small volume of ammonium carbonate solution, to precipitate calcium carbonate, and it was then evaporated to dryness on a steam bath. Ammonia salts were then expelled by heating for an instant to dull redness. The residue was taken up with water, and the resulting solution was filtered into tared platinum dishes; hydrochloric acid was added, the solutions were evaporated to dryness on a steam bath, the dishes and their contents were heated for an instant to dull redness, and were cooled in a desiccator. The weight of the solids was taken as soluble salts.

The soluble salts were dissolved in water, the solution was transferred to a graduated flask and was diluted to 50 cubic centimeters. Portions of this, 10 cubic centimeters in volume, were subsequently analyzed for potassium by the chlorplatinic acid method.

The residue of charcoal left on the filter after the first filtration was ignited to whiteness. Its weight was recorded as ash.

The weight of the soluble salts, plus that of the ash, when subtracted from the original weight of the sample gives a value which obviously represents organic matter.

*Iodine.*—Portions of the ground material, 2 grams in weight, were incinerated and lixiviated in the manner described in a foregoing paragraph.

The filtered solution was transferred to a separatory funnel of 250 cubic centimeters capacity containing 10 cubic centimeters of a solution of sulphuric acid (10 c. c. conc.  $\text{H}_2\text{SO}_4$ : 90 c. c.  $\text{H}_2\text{O}$ ) and 10 to 15 cubic centimeters pure carbon tetrachloride. The solution was titrated with a solution of potassium permanganate, previously standardized against pure potassium iodide, the manipulation during the standardization being identical with that employed in the actual analysis.<sup>1</sup>

The persistence in the solutions of the pink color of the permanganate was taken as the end point.

The potassium iodide used for the purpose of standardization was purified by recrystallization. It was dried for several hours at 107° C., and was cooled and preserved in a desiccator. One gram of this material was dissolved in 1 liter of water. This was titrated in volumes of 100 to 5 cubic centimeters, and in smaller volumes prepared by diluting a measured portion of it to definite volumes and by taking portions of the more dilute solution for titration. Thus values were obtained through a range which represented a percentage, on the basis of a 2-gram sample, of 5 to 0.05. The values obtained were quite consistent down to the extremely small samples, where the amount of permanganate solution necessary to give a coloration, perhaps a tenth of a cubic centimeter, introduced an appreciable error. On that account the method lacks accuracy in the determination of extremely small amounts of iodine, unless, indeed, the amount of permanganate necessary to effect an end point is determined and a correction is made therefor.

This method, which is based on the direct titration of potassium iodide by permanganate, is applicable only in the absence of other

<sup>1</sup> Cf. Bray and MacKay, J. Am. Chem. Soc., 32, 1139 (1910).

substances oxidizable by permanganate. That this condition is observed in the method of analysis described is indubitable. The incineration of the kelp is performed at too low a temperature, probably, for the carbon present to reduce, for example, the sulphates present to sulphides or the phosphates to phosphides; and, furthermore, with stirring, the excess of oxygen is sufficient to reoxidize those substances if formed. All organic matter undoubtedly is completely broken down. The first drop of permanganate effects a liberation of iodine which imparts a distinct color to the solution, and when the brown of iodine no longer appears the pink of the permanganate persists.

After one has acquired some experience with the method, the relative iodine content of the samples undergoing analysis can be followed by noting the intensity of the coloration of the carbon tetrachloride layer. The entire absence of iodine is very sharply indicated in this way, and its presence in very small amounts as well.

The method, then, is recommended for use where speed in the analysis is desired, and it is fully believed that it is capable of giving accurate results under the right conditions.

TABLE I.—Analyses of Pacific kelps by J. W. Turrentine.

B. of S. No.	Serial No.	Name of kelp.	Location.	Description of sample.	Potash (K <sub>2</sub> O).	Iodine (I).	Nitrogen (N).	Soluble salts (Na KClO <sub>3</sub> ).	Sodium salts, estimated.	Organic matter.	Ash of leached plant.	KCl.
					Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	R 1	Nereocystis luetkeana.	San Juan County, Wash.	Stipe.	25.7	0.08	1.29	55.9	15.3	41.5	2.3	40.6
2	R 2	Laminaria bullata.	do.	do.	15.9	.41	1.99	35.8	11.6	57.4	5.8	25.2
3	R 4	Agarum fimbriatum.	do.	do.	12.2	.12	1.90	28.7	9.4	60.3	11.0	19.3
4	R 5	Laminaria bullata.	do.	do.	10.4	.29	1.90	25.0	8.6	60.4	14.6	16.4
5	R 6	Nereocystis luetkeana.	do.	Fronds.	15.9	.15	2.82	35.0	14.0	61.5	3.5	26.7
6	R 7	Laminaria saccharina.	do.	do.	16.9	.41	1.64	35.6	8.9	66.9	17.4	14.5
7	R 8	Alaria valida.	do.	do.	9.2	.08	1.94	28.4	11.9	65.3	6.7	36.4
8	R 9	Nereocystis luetkeana.	do.	Fronds.	23.0	.17	1.35	51.3	14.9	48.3	2.5	31.3
9	R 10	Desmarestia ligulata, herbacea.	do.	do.	13.5	.12	1.75	41.9	20.6	48.3	9.8	21.3
10	R 11	Laminaria bullata.	do.	do.	11.0	.35	1.95	28.4	9.0	64.0	9.6	17.4
11	R 12	do.	do.	do.	16.4	.41	2.01	37.9	12.0	55.4	5.7	25.9
12	R 13	Laminaria saccharina.	do.	do.	17.8	.53	1.75	33.4	10.3	50.3	11.3	23.1
13	R 14	Pleurophycus gardneri.	do.	do.	6.9	.12	1.82	26.5	15.6	54.7	8.2	10.9
14	R 15	Fucus evanesceus.	do.	do.	8.1	.06	1.66	20.1	15.1	75.3	4.1	4.9
15	R 16	Egregia menziesii.	do.	do.	13.3	.08	2.35	30.4	9.4	61.2	5.4	21.0
16	R 17	Costaria turneri.	do.	do.	17.0	Trace	1.81	39.1	12.2	54.6	6.3	26.9
17	R 18	Agarum fimbriatum.	do.	do.	12.4	.07	1.95	29.5	9.9	60.2	10.3	19.6
18	R 19	Desmarestia ligulata, herbacea.	do.	do.	6.2	.06	2.25	24.3	14.5	66.7	6.0	9.8
19	R 20	Cymathere triplicata.	do.	do.	13.4	.06	1.40	32.0	11.0	58.3	9.7	21.0
20	R 21	Laminaria saccharina.	do.	do.	15.4	Trace	1.75	35.3	10.4	50.4	13.3	25.9
21	R 22	Nereocystis luetkeana.	do.	do.	16.2	.15	2.32	40.4	14.8	55.3	4.3	25.6
22	R 23	Fucus evanesceus.	San Juan County, Wash.	Fronds.	3.1	None.	1.59	19.0	14.1	77.9	4.7	4.9
23	R 24	Cymathere triplicata.	do.	do.	13.8	Trace.	1.56	34.6	12.8	59.7	5.0	21.8
24	R 25	Pleurophycus gardneri.	do.	do.	7.3	.12	1.85	27.0	15.5	65.0	8.0	11.5
25	R 26	Egregia menziesii.	do.	do.	10.3	.07	2.49	32.1	15.8	60.3	7.6	16.3
26	R 27	Postelsia palmaeformis.	Neah Bay, Wash.	Fronds.	13.9	.15	1.88	29.9	7.9	64.4	5.7	22.0
27	R 28	Macrocystis pyrifera.	do.	do.	19.6	.20	1.81	32.5	1.5	51.5	16.0	31.0
28	R 29	do.	do.	do.	14.0	.22	2.18	30.4	7.3	49.6	19.2	22.1
29	R 30	Pterygophora californica.	do.	Stipe.	37	.....	.....	14.8	14.2	.....	5.2	22.1
30	R 31	Postelsia palmaeformis.	Yakutat, Alaska.	do.	20.0	.17	1.01	41.1	9.5	54.9	4.0	31.6
31	J 1	Rhodomenia palmata linearis.	Yakutat, Alaska.	Entire plant.	2.8	None.	.....	7.2	2.8	91.0	1.8	4.4
32	J 2	Fucus evanesceus macrocephala.	Sitka, Baranof Island, Alaska.	do.	2.7	None.	.....	16.3	12.0	81.1	2.6	4.3
33	J 3	Fucus evanesceus ag. forma.	do.	do.	2.9	( <sup>1</sup> )	.....	13.9	9.3	82.7	2.4	4.6
34	J 6	Alaria (lanceolata ?)	Blorka Island, Symonds Bay, Alaska.	Portion of plant.	3.0	.12	.....	13.5	8.3	77.9	8.6	4.7
35	J 7	Macrocystis pyrifera.	do.	do.	3.1	.23	1.96	26.3	20.3	70.6	4.2	4.9
36	J 8	Cystophyllum gemmatum.	do.	do.	7.3	.26	1.95	27.0	15.5	64.7	8.3	11.5

37	J 9	<i>Alaria lanceolata</i>	Sitka, Baranof Island, Alaska	do	Trace	13.5	8.1	79.4	7.1	5.1
38	J 10	<i>Halosaccion glandiformis</i>	do	do	Trace	24.1	13.8	70.1	5.8	10.3
39	M 1	<i>Postelsia palmaeformis</i>	Montara Point, Cal.	Dried stems	Trace	44.5	8.5	52.3	5.8	34.0
40	M 2	<i>Macrocystis pyrifera</i>	Montery Bay, Cal.	do	Trace	35.7	8.8	87.0	7.3	23.8
41	M 3	<i>Egria manziellii</i>	Point Pinos, Cal.	do	Trace	26	6.9	86.6	6.7	18.9
42	M 4	<i>Macrocystis pyrifera</i>	Off Point Anlon, Cal.	do	Trace	27.7	7.0	51.2	5.5	34.3
43	M 5	<i>Fucus lucutatus</i>	Point Alones, Cal.	do	Trace	43.3	14.8	73.2	4.3	7.7
44	M 6	<i>Postelsia palmaeformis</i>	Montara Point, Cal.	Fron	Trace	22.5	14.4	66.0	4.3	15.3
45	M 7	<i>Gilgintina radula</i>	Montara Point, Cal.	do	Trace	29.7	14.4	72.1	3.4	6.2
46	M 8	<i>Fucus evanescent</i>	Point Alones, Cal.	Thallus	Trace	24.5	18.3	76.1	4.4	8.8
47	M 9	<i>Nereocystis luetkeana</i>	Point Pinos, Cal.	do	Trace	20.5	11.7	83.1	4.1	30.7
48	M 10	<i>Dictyonuron californicum</i>	do	do	Trace	42.8	12.1	83.1	6.9	24.2
49	M 11	<i>Costaria turneri</i>	Point Alones, Cal.	do	Trace	33.1	8.9	80.0	6.9	24.2
50	M 12	<i>Nereocystis luetkeana</i>	Off Point Pinos, Cal.	Stipes and float	Trace	30.5	7.7	61.0	8.5	22.8
51	M 13	<i>Gilgintina spinosa</i>	Montery Bay, Cal.	do	Trace	55.5	14.3	40.6	3.9	41.2
52	M 14	<i>Laminaria andersonii</i>	Near Point Pinos, Cal.	do	Trace	25.9	11.4	70.5	3.6	14.5
53	S 1 Cr	<i>Macrocystis pyrifera</i>	Station 1 (Sheet XVIII)	Stipes and fronds	Trace	19.4	9.4	75.8	4.8	10.0
54	S 2 Cr	do	Station 2 (Sheet XVIII)	do	Trace	35.0	10.1	60.9	4.1	24.9
55	S 3 Cr	do	Station 3 (Sheet XVIII)	do	Trace	31.2	10.0	63.9	5.9	21.2
56	S 4 Cr	do	Station 4 (Sheet XVIII)	do	Trace	29.3	8.1	66.7	4.0	21.2
57	S 5 Cr	<i>Pelopagophycus porra</i>	Station 5 (Sheet XIV)	do	Trace	30.6	8.2	64.4	5.0	21.4
58	S 6 Cr	<i>Macrocystis pyrifera</i>	do	do	Trace	28.6	10.5	65.5	4.9	19.1
59	S 7 Cr	do	Station 6 (Sheet XIV)	do	Trace	38.1	9.0	67.3	3.9	19.8
60	S 8 Cr	do	Station 7 (Sheet IX)	do	Trace	30.2	6.1	63.7	6.1	21.7
61	S 9 Cr	do	Station 8 (Sheet IX)	do	Trace	28.9	8.5	66.2	4.9	19.4
62	S 10 Cr	do	Station 9 (Sheet IX)	do	Trace	29.0	9.9	61.8	9.2	19.1
63	S 11 Cr	do	Station 10 (Sheet IX)	do	Trace	28.5	8.1	64.8	6.7	20.4
64	S 12 Cr	do	Station 11 (Sheet IX)	do	Trace	31.2	15.7	65.1	4.7	15.5
65	S 13 Cr	do	Station 12 (Sheet IX)	do	Trace	36.6	10.2	56.7	6.7	26.4
66	S 14 Cr	do	Station 13 (Sheet IX)	do	Trace	32.2	9.9	63.5	4.3	26.3
67	S 15 Cr	do	Station 14 (Sheet IX)	do	Trace	36.3	9.6	58.3	5.4	26.7
68	S 16 Cr	do	Station 15 (Sheet IX)	do	Trace	30.4	10.5	64.4	5.2	19.9
69	S 17 Cr	do	Station 16 (Sheet IX)	do	Trace	44.1	16.6	49.4	6.5	27.5
70	S 18 Cr	do	Station 17 (Sheet IX)	do	Trace	39.0	11.5	56.7	5.3	37.6
71	S 19 Cr	do	Station 18 (Sheet IX)	do	Trace	41.2	15.3	50.6	8.1	25.9
72	S 20 Cr	do	Station 19 (Sheet IX)	do	Trace	22.1	8.8	71.7	6.2	13.8
73	S 21 Cr	<i>Pelopagophycus porra</i>	Station 20 (Sheet XIII)	Young plant	Trace	41.0	10.2	52.4	6.6	30.8
74	S 22 Cr	do	do	Leaves	Trace	37.38	12.8	56.2	6.4	24.6
75	S 23 Cr	do	do	Bulbs	Trace	33	13.1	47.5	3.0	47.6
76	S 24 Cr	<i>Macrocystis pyrifera</i>	do	Stems	Trace	40.3	10.7	54.6	3.8	28.6
77	S 25 Cr	do	do	Stems and leaves	Trace	28.2	8.7	61.9	10.9	18.9
78	S 26 Cr	do	do	do	Trace	23.6	11.9	61.3	10.1	16.7
79	S 27 Cr	do	do	do	Trace					
80	S 28 Cr	do	do	do	Trace					
81	S 29 Cr	do	do	do	Trace					
82	S 30 Cr	<i>Pelopagophycus porra</i>	Station 20 (Sheet XIV)	do	Trace	19.2	7.7	76.3	4.5	11.5
83	S 31 Cr	do	do	do	Trace	27.95	12.4	67.0	5.1	34.1
84	S 32 Cr	do	do	do	Trace	46.8		48.4	4.8	

**Faint trace.**

## DISCUSSION OF ANALYTICAL DATA.

In the second column are given the serial numbers of the kelp samples examined. It will be noted that there are four series, consisting of the four collections of samples secured during the summer of 1911. The series designated by the capital S is from the Crandall collection, from the extreme southern coast of California. The other three are designated by the initial letter of the surname of the collector: M, McFarland, whose samples are from the Monterey Bay region; R, Rigg, who surveyed the Puget Sound district; and J, Johnston, of the *Albatross*, through whom the specimens of Alaskan kelps were secured.

In the third column are recorded the names of the kelps analyzed. It will be noted that while kelps from the Puget Sound survey include numerous varieties, those from the most southern survey (Crandall's) include only two varieties, the two giant kelps of that region, *Macrocystis* and *Pelagophycus*.

In the fourth column are indicated the locations from which any particular specimen was taken. In many instances the locus is given with precision. Crandall has marked on the maps as stations the points from which his samples were taken and has "placed" each station in degrees, minutes, and seconds.

When the sample examined was of some special part of the plant, that fact is indicated in the fifth column. Where no statement is made concerning the nature of the sample it should be understood that it is composed of the leafy parts, where the kelp is one of the large varieties, or of the entire plant where the specimen is a young plant or is one of the smaller kelps. Thus the samples of the southern *Macrocystis* consisted, in practically every instance, of branches, or fronds, bearing leaves and floats.

In the sixth column the potassium content of the kelps is recorded as the oxide,  $K_2O$ . In a later column it is calculated to potassium chloride, which more nearly represents the condition in which it actually occurs in the plant. Here is recorded the potassium content of every sample analyzed. It should be borne in mind that the majority of these varieties can not be considered as a commercial source of potash, not on account of their low potash content, for even the ones containing the smallest percentage of potash contain more of that substance than do many of the Atlantic kelps used for centuries as a source of potash for agricultural purposes, but because they are of the smaller varieties and occur in smaller amounts. It is only in the case of the giant kelps and a few smaller ones occurring in large amounts that the average potash content is of any moment. The varieties *Macrocystis*, *Nereocystis*, *Pelagophycus*, and *Postelsia* alone should be considered. These show an average content of 23.4 per cent potassium chloride and 0.29 per cent iodine.

The soluble salts in the ninth column represent the weights of the combined sodium and potassium chlorides and sulphates. The solution from which these were crystallized had been treated with ammonium carbonate to precipitate calcium. Magnesium salts are also included. In the test analyses it was found that there were but negligible amounts of both calcium and magnesium salts in the solution obtained on lixiviating the charred kelp. Whether it is safe to conclude that the lixiviate from the char of every kelp is so free from

calcium and magnesium salts is an open question. It is the writer's opinion that the question is answerable in the affirmative. In very rare cases did the addition of ammonium carbonate to the lixivate produce any precipitations of calcium carbonate whatever. This shows a constant freedom from calcium salts and may be taken, by analogy, as an indication of a similar absence of magnesium salts.

In every instance where a test was made sulphates were found to be present.

In the tenth column the "estimated" sodium salts are recorded. These values are mere estimates and may, and in some cases most probably do, distort the truth. They are obtained by subtracting the percentage of potassium chloride from the percentage of soluble salts. Were both potassium and sodium present as chloride alone, in the absence of magnesium these values should be accurate. It is known, however, that considerable amounts of sulphate are present. This has been shown by Balch. To calculate the potassium to chloride, when it is present wholly or in part as sulphate, throws the entire error introduced upon the sodium and makes the latter appear disproportionately large. The loss in weight on charring and ignition, converted to the percentage basis, is given in the eleventh column as organic matter. This is obtained by subtracting the sum of the soluble salts and ash from the weight of the sample taken.

The ash (twelfth column) is not the inorganic residue obtained on igniting the kelp as the ignition is usually conducted, but is the result of the incineration of the char after it has been thoroughly lixiviated. It is the water insoluble, inorganic constituents of the kelp, and consists of silica, resulting largely, probably, from sea sand entangled with the kelp; calcium carbonate (or oxide, depending on the intensity of the ignition), from the plant itself, or from minute barnacles or other calciferous organisms growing on or entangled among them; magnesia; small amounts of sodium and potassium salts, present through imperfect lixiviation, and such acid radicals as the phosphate and possibly the sulphate. Carbonates would result from the combustion, with any free alkali or alkaline earth present. It may be noted in this connection that the lixivate gives an alkaline reaction when tested with litmus, which fact indicates that there is not enough of the nonvolatile, inorganic acid radicals to neutralize completely the bases present.

#### SEAWEEDS OF VARIOUS ORIGINS.

In the days of the iodine-from-kelp industry the composition of marine algae was studied from the viewpoint of that industry and by analysts interested in that industry. In later years interest has centered rather on the manurial value of the sea plants. Accordingly, reports on the subject are to be found in the literature of the agricultural experiment stations.

Perhaps the most striking result of a cursory examination of the various plants analyzed is the wide variation in their composition. A considerable variation would result, anyway, because of the fact that the taking of samples was not done in accordance with standardized methods; that, in instances, the saline constituents may have been—and doubtless were—removed partially through leaching having taken place before the samples were collected, and that the per-



sonal equation of the analyst would introduce a disparity in the results of analysis of samples of similar composition.

(1) The various varieties of kelps vary widely in their relative as well as actual contents of inorganic salts.

(2) The ratio between the amounts of inorganic salts in the seaweeds is not the same as in sea water, showing a selective absorption. Thus potassium may equal or exceed sodium; in some instances, notably among the Pacific kelps, potassium salts are present almost to the exclusion of sodium salts and iodine exceeds bromine. In sea water, it is remembered, sodium is present in very much greater amounts than potassium, and bromine than iodine.

(3) One may expect to find in any seaweed the following: Potassium, sodium, calcium, and magnesium, and the nonmetals chlorine, bromine, iodine, phosphorus, and sulphur, in addition to those entering more commonly into the composition of organic compounds, viz, hydrogen, oxygen, carbon, and nitrogen.

(4) Variations in composition are to be found between specimens of the same species from different localities, of the same species growing closely together, of the same species at different ages, and very marked differences between the different parts of a single plant.

When these variables are considered, together with those mentioned in a former paragraph, it is seen that concordant results in the analysis of sea plants is scarcely to be expected. In the succeeding paragraphs will be quoted analyses of seaweeds from various parts of the world. While the analyses are chosen to a certain extent at random, they are believed to be typical.

Analyses of American kelps are divided into two groups, those from the Atlantic and those from the Pacific coast. In the latter group are recorded those performed in this laboratory.

*Scotland.*—The analysis of a specimen of Scotch kelp ash is given in the following table:

TABLE II.—*Analysis of Scotch kelp ash.*

	Per cent.		Per cent.
K <sub>2</sub> SO <sub>4</sub> .....	23.08	Insoluble matter .....	43.71
KCl .....	1.45	Water .....	6.22
NaCl .....	19.13	Potash (K <sub>2</sub> O) .....	13.40
Na <sub>2</sub> CO <sub>3</sub> .....	6.48	Iodine <sup>1</sup> .....	.18

Scotch kelp ash is compared with that from California (analyses by Balch):

Potassium salts:	Per cent.
Scotch .....	24.53
California .....	71.8
Ratio, 1:3.	

*England.*—The following results are from analyses of three varieties of the Fuci, and are published by Barlow:<sup>2</sup>

<sup>1</sup> 4.14 pounds per ton.

<sup>2</sup> Cooper Laboratory of Economic Research, Watford; J. Board Agric., 17, 832 (1911).

TABLE III.—*Analysis of Fuci.*

Constituent.	<i>F. nodosus.</i>	<i>F. serratus.</i>	<i>F. vesiculosus.</i>
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Organic matter.....	73.99	76.97	71.85
Ash.....	26.01	23.03	28.65
Nitrogen.....	1.78	2.88	2.29
Potassium.....	4.47	5.00	6.29
Phosphoric acid.....	.29	.55	.45

The content of alkalis—calculated as oxides of sodium and potassium—of the kelp ash is given in Table IV:

TABLE IV.—*Analyses of Fuci for alkali.*

Plant.	Na <sub>2</sub> O	K <sub>2</sub> O	Total.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
<i>Fucus nodosus</i> .....	23.19	17.19	40.38
<i>Fucus serratus</i> .....	17.76	21.69	39.45
<i>Fucus vesiculosus</i> .....	18.72	21.94	40.66

The analyses reported in Table V were made by Russell.<sup>1</sup>

TABLE V.—*Analyses of seaweeds from British Isles.*

Constituent.	<i>Fucus ceranoides</i> , Croyde, North Devon, July, 1906.	<i>Fucus canaliculatus</i> , Croyde, North Devon, July, 1908.	<i>Fucus serratus</i> , Thanet, Kent, Feb., 1909.	<i>Fucus</i> , Jersey, Mar., 1907.	Laminaria.		Green weeds.	
					Thanet, Kent, Feb., 1909.	Jersey, Mar., 1907.	<i>Cladophora</i> and <i>Ulva</i> , Croyde, North Devon, July, 1908.	<i>Ulva</i> , Thanet, Kent, Feb., 1909.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Organic matter.....	69.80	76.00	75.16	73.86	61.66	63.59	.....	.....
Nitrogen.....	1.25	1.53	2.33	2.25	2.14	1.48	1.68	2.70
Total ash.....	30.20	24.00	24.84	26.14	38.34	36.41	.....	.....
Sand.....	6.15	2.67	3.73	1.24	13.15	1.14	.....	.....
Pure ash.....	25.05	21.33	21.11	24.90	25.19	35.27	.....	.....
Phosphoric acid.....	.03	.03	.05	.66	.06	.65	.03	.....
Potash.....	3.80	2.52	3.70	5.88	4.74	5.76	2.16	.....

The samples of *Fucus* from Jersey and from Croyde and the *Cladophora* were cut from the rocks; the Thanet sample of *Fucus*, the *Laminaria*, and the *Ulva* were thrown up by the tides.

The composition of seaweed apparently varies with the seasons. This fact is brought out in analyses of Jersey seaweeds by Tom (Notes on Farm Chemistry in Jersey, 1905). These are given in Table VI.

<sup>1</sup> Cf. Leaflet 254, Board Agric. and Fisheries, p. 3.

TABLE VI.—*Analyses of Jersey seaweeds.*

Time of cutting.	Fresh weed, per cent.		Percentage composition of dry matter.					
	Water.	Dry matter.	Organic matter.	Nitrogen.	Ash.	Potash.	Lime.	Phosphoric acid.
<i>Fucus</i> (cut):	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
March .....	77.4	22.6	81.4	1.91	18.6	2.62	1.3	0.36
May .....	73.4	26.6	79.5	1.98	20.5	2.26	2.1	.20
October .....	76.6	23.4	79.3	1.16	20.7	2.50	1.3	.85
<i>Laminaria</i> (drift):								
March .....	87.0	13.0	65.0	3.06	35.0	3.45	1.96	1.29
May .....	78.0	22.0	74.0	1.94	25.6	3.93	1.70	1.70
October .....	82.0	18.0	81.7	.96	19.3	2.34	1.65	1.65

*Scotland, England* (for iodine only).—The following table (Table VII) gives results of analyses of various sea plants, by different analysts, for the element iodine.<sup>1</sup> The figures represent per cent iodine in the dry plant:

TABLE VII.—*Iodine content of various seaweeds.*

Plant.	Sarphat.	Schweitzer.	Godechens.	Wallace.	Zenger.	Stanford.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1. <i>Laminaria digitata</i> .....	0.135		0.625	0.444		0.4535
2. <i>Laminaria saccharina</i> .....	.230	3.880		.288		.2946
3. <i>Fucus serratus</i> .....	.124	.058	.177	.0565		.2794
4. <i>Fucus nodosus</i> .....			.074	.0396		.0856
5. <i>Fucus vesiculosus</i> .....	.001					.0572
6. <i>Zostera marina</i> .....	.0005					.0457
7. <i>Rhodomela pinastroides</i> .....						.0378
8. <i>Hyderix siliquosa</i> .....						.2131
9. <i>Hymanthalia lorea</i> .....						.0892
10. <i>Chordaria flagelliformis</i> .....						.2810
11. <i>Cladophora glomerata</i> (fresh water) .....					.0227	

The two results given in the Stanford column for *Laminaria digitata* are for samples of stems and fronds, respectively; the former figure is the average of 18 specimens and the latter of 23 specimens. Samples Nos. 2, 3, 4, and 5 are the average of 5, 12, 4, and 8 specimens, respectively.

The specimens analyzed by Stanford were taken from Larne, Ballina, Sligo, Galway, and Skibereen, in Ireland; Shetland, Call, Colonsay, Tobermory, Vallay, Baleshare, Burreray, Neisker, Stornoway, Skye, Tyree, Kilreggen, Iona, Dunbar, and Fife, in Scotland; Scarborough, Weymouth, and Worthing, in England; Peele, in the Isle of Man; and also from Norway, Denmark, and Iceland. The first five varieties are those which were employed in making kelp ash.

The origin of the specimens examined by the other analysts is not given.

*France*.—Marchand and Knauss found that iodine in the *Fuci* varied between 0.66 and 5.35 per cent. Marchand collected specimens in the harbor of Fécamp which contained 0.2 to 1.01 per cent bromine, 6.07 to 15.15 per cent potash, 14.23 to 38 per cent soda.

<sup>1</sup> Stanford, Chem. News, 85, 172 (1877). See p. 173.

These results have been confirmed by Cuniasse (Chem. Zentr., 1900, 2 (4), 286), who has divided the algae of that region into two classes, as follows:

Constituent.	Class 1.	Class 2.
	<i>Per cent.</i>	<i>Per cent.</i>
Bromine.....	0.19- 0.42	0.04- 0.16
Iodine.....	.6- 1.4	.07- .16
Potash.....	8.7-23	11.0-18.2
Soda.....	8.0-20.5	8.5-16.25

*Japan.*—Kinch has made a study of some of the principal seaweeds of Japan that are used as food. The following quotation is from his report, entitled "Contributions to the Agricultural Chemistry of Japan."<sup>1</sup> Numerous pertinent and interesting comments are included in the quotation.

Nori and Asakusa Nori are the names specially given to *Porphyra vulgaris* (Agardh.), the alga which supplies the principal part of that sold in England under the name of laver, in Ireland as sloke, and in Scotland as slaak. This is, as is well known, cultivated in the shallow water of Tokyo Bay on branches of oak, *Quercus serratus*, and other trees, the crop being gathered in the winter months; in the summer it becomes too tough for use. The water at Asakusa has for nearly three centuries been too fresh for its cultivation in the river there, but the name is still retained.

45. *Asakusa Nori, Porphyra vulgaris* (Agardh.).—Best kind from Omori, near Tokyo; 100 grams cost 36 sen.

46. *Asakusa Nori, Porphyra vulgaris* (Agardh.).—Medium quality from Omori, near Tokyo; 100 grams cost 29 sen.

47. *Asakusa Nori, Porphyra vulgaris* (Agardh.).—Common variety from Omori, near Tokyo; 100 grams cost 3 sen.

48. *Nori, purple color, Porphyra vulgaris* (Agardh.).—From Uwagori, Iyo, Yehime ken; 100 grams cost 27 sen.

49. *Nori, purple color, Porphyra vulgaris* (Agardh.).—From Shikichi-gori, Enshu, Shidzouka ken; 100 grams cost 18 sen.

50. *Nori, green laver, probably Phycoseris australis* (Kützinger).—From Ise; 100 grams cost 5 sen.

TABLE VIII.—Percentage composition of Japanese seaweeds.

Constituent.	45	46	47	48	49	50
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	14.40	12.00	19.40	12.98	12.91	15.61
Ash.....	9.45	6.80	11.90	8.68	8.64	16.73
Fiber.....	5.50	5.66	7.46	9.83	9.98	8.71
Nitrogenous substances.....	26.14	18.11	4.48	17.41	19.88	6.32
Nonnitrogenous substances.....	44.51	56.83	57.71	51.10	48.59	52.63
	100.00	100.00	100.00	100.00	100.00	100.00
Containing nitrogen.....	4.13	2.86	.66	2.75	3.14	1.33
Ash contains—						
Silica.....	1.40	.60	7.80	6.40	6.65	1.96
Phosphoric acid.....	14.07	13.77	6.05	13.27	14.16	7.25
Potash.....	34.50	31.50	11.15	35.19	33.83	32.27

The green laver is inferior to the purple.

It will be noticed that the price is very nearly in the same order as the quantity of nitrogen, which decreases with the age of the plant.

Another common seaweed, kobu, is *Laminaria saccharina* (Lamouroux) or sweet tangle, or a closely allied species, *L. japonica* (Aresch.). This is closely

<sup>1</sup> Trans. Asiatic Society of Japan, 8 (III), 369 (1880).

allied to the common tangle *L. digitata* (Lamour.), known also in different parts of the United Kingdom as sea girdles, redware and sea wand. Tangle is the species which supplies the largest amount of kelp. The stem is used for knife-handles and the plant often as a hygrometer in England. Both *L. saccharina* and *L. digitata* contain a peculiar kind of sugar apparently identical with that occurring in manna and in some other plants, called mannite. Sweet tangle contains 12 to 15 per cent of this sugar.

51. *Kobu*.—From Yezo.

52. *Kobu*.—From Toshiki-gori, Wakasa, Shiga ken.

TABLE IX.—Percentage composition of *kobu*.

Constituent.	51	52
	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	26.80	24.82
Ash.....	22.50	18.53
Fiber.....	9.33	4.97
Nitrogenous substances.....	7.79	6.02
Nonnitrogenous substances.....	33.58	45.66
	100.00	100.00
Containing nitrogen.....	1.23	.95
Ash contains—		
Silica.....	3.94	Trace.
Phosphoric acid.....	4.43	2.96
Potash.....	27.00	31.77

*Kobu* is also used as an emblem of a present.

Another species is wakame, *Alaria pinnatifida* (Harvey); its British congener, *A. esculenta* (Greville), is known in various parts of Scotland as bladderlocks or badderlocks (balderlocks), henware, honeyware, and murlins. It is used as food on the coast of Scotland and Ireland and in Denmark and Iceland, and is one of the best of the esculent algae. Arame, or kokusai, is perhaps *Capea elongata*; awo-nori, or ohashi-nori, is *Enteromorpha compressa* (Grev.), a species growing in fresh and salt water, especially on tidal rocks.

Hijiki, a species of *Cystoseira* (?), is found on all the coasts; that from Ise is most valued. Besides these many other species are used to a less extent, and tokoroten-gusa, sometimes called agar-agar, *Gelidium corneum* (Lamour.), is largely employed in the manufacture of kanten or tokoroten, vegetable isinglass.

53. *Wakame*.—One hundred grams cost 6.5 sen.

54. *Arame*.—From Shinano; 100 grams cost 1.2 sen.

55. *Awo-nori*.—From O-hashi, Tokyo; 100 grams cost 7.5 sen.

56. *Hijiki*.—From Iwachi-mura, Kamogori, Idzu; 100 grams cost 2.5 sen.

TABLE X.—Percentage composition of certain seaweed products.

Constituent.	53	54	55	56
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	15.11	13.17	13.60	16.40
Ash.....	33.82	24.74	10.42	16.20
Fiber.....	2.16	7.40	10.58	17.06
Nitrogenous substances.....	8.29	8.99	12.41	8.42
Nonnitrogenous substances.....	40.62	45.09	52.99	41.92
	100.00	100.00	100.00	100.00
Containing nitrogen.....	1.32	1.42	1.93	1.33
Ash contains—				
Silica.....	Trace.	6.97	2.20	1.91
Phosphoric acid.....	2.61	11.22	2.37	2.20
Potash.....	21.00	27.98	.....	32.55

The cultivation of seaweed is carried on extensively in some places, and it is said that a great number of varieties arise from the different trees which are used as the feeding ground of the plants, which include different varieties of oak, other deciduous trees, and bamboos.

*American, Atlantic.*—The following table contains results of analyses of five varieties of seaweeds from Milford, Conn. The analyses were made at the Connecticut State Experiment Station, and appear in the annual report of that station for 1890. (See p. 72.)

The samples analyzed were as follows: (1) Broadstalked rockweed, *Ascophyllum nodosum*; (2) flatstalked rockweed, *Fucus vesiculosus*; (3) a coarse "sponge," species not determined; (4) a finely-branching seaweed, species not determined; (5) "Irish moss," *Chondrus crispus*.

TABLE XI.—Analysis of Connecticut seaweeds.

Constituent.	1	2	3	4	5
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	82.71	84.34	86.13	81.39	80.84
Volatile matter.....	13.52	12.09	5.46	12.72	14.43
Pure ash.....	3.97	3.57	8.41	5.89	4.73
Nitrogen.....	.53	.48	.58	.73	.77
Potash.....	.61	.54	.16	1.30	1.00
Soda.....	.90	.85	.72	.58	.....
Lime.....	.30	.27	.08	.23	.....
Magnesia.....	.24	.23	.14	.18	.....
Oxide iron and aluminium.....	.10	.02	.23	.12	.....
Phosphoric acid.....	.10	.09	.14	.18	.17
Sulphuric acid.....	.82	.67	.17	.84	.....
Chlorine.....	.80	.82	.77	.96	.....
Silica.....	.12	.16	6.17	1.72	.54

Table XII contains results of analyses of rockweed, green and dry, of wet kelp, and of seaweed ashes.<sup>1</sup>

TABLE XII.—Analyses from Massachusetts State Experiment Station.

Constituent.	Rockweed.		Wet kelp.	Seaweed ashes.
	Green.	Dry.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Moisture (at 100° C.).....	68.50	10.68	88.04	1.47
Ash.....	23.70	55.75	2.26	.....
Calcium oxide.....	.....	7.66	.....	6.06
Magnesium oxide.....	.....	.21	.....	4.37
Potassium oxide.....	.....	4.89	.....	.92
Sodium oxide.....	.....	7.90	.....	8.76
Phosphoric acid.....	.....	2.75	.....	.30
Nitrogen.....	.96	1.45	.26	.....
Insoluble matter.....	.....	10.40	.....	63.65
Sulphuric acid.....	.....	.....	.....	2.98
Chlorine.....	.....	.....	.....	6.60

The seaweeds of the Atlantic coast have been investigated especially by Wheeler and Hartwell of the Rhode Island Experiment Station. For their interesting discussion of the agricultural value and chemical composition see Bulletin 21, 1893.

The following table (Table XIII) is quoted from this bulletin. It gives analyses of seaweed from the vicinity of Point Judith, R. I., and by other analysts of plants from certain other localities on the coast of New England and of Europe.

<sup>1</sup>Cf. Mass. State Expt. Sta. Record, 1887, p. 223.

TABLE XIII.—Wheeler and Hartwell's compilation of analyses of seaweeds.

Name of seaweed, botanical and common.	Month of collection.	Nitrogen.	P <sub>2</sub> O <sub>5</sub> .	K <sub>2</sub> O.	CaO.	MgO.	Source of specimen.
		<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
<i>Ascophyllum (fucus) nodosum</i> ; Round-stalked rockweed.	January.....	1.50	0.38	2.93	2.03	1.54	Rhode Island.
	March.....	1.18	.38	2.77	2.10	1.50	Do.
	September..	.64	.30	2.74	2.28	1.54	Do.
	.....	.32	.22	1.46	1.86	1.50	
	.....	.32	.87	1.79	1.24		Scotland (?).
	.....	1.75	.38	3.16	1.77	1.83	
	March.....	3.06	.58	3.52	1.74	1.39	Connecticut.
	.....	2.03	.45	2.05	1.67	1.24	Rhode Island.
	March.....	1.93	.60	2.77	2.04	1.34	Do.
	September..	.82	.40	3.14	1.84	1.22	Do.
<i>Fucus vesiculosus</i> ; Flat-stalked rockweed.	.....	.19	.22	1.12	1.36	.99	
	.....	.....	.84	2.64	2.07	1.87	Liverpool.
	.....	1.09	.37	3.61	1.15	1.67	Denmark.
	.....	.45	1.32	1.54	1.01	1.01	Scotland (?).
	.....	1.09	.35	1.40	2.50	2.50	Baltic Sea.
	.....	3.06	.57	3.45	1.71	1.71	North Germany(?)
	March.....	1.22	.34	.95	1.73	1.47	Connecticut.
	.....	.....	.....	.....	2.22	1.01	Normandy.
	.....	1.85	.....	.....	.....	.....	Rhode Island.
	March.....	1.99	.46	2.83	2.76	1.55	Do.
<i>Laminaria saccharina</i> ; Ribbon weed, kelp, tangle.	September..	.94	.35	.80	3.28	1.39	Do.
	.....	1.75	.58	1.10	1.49	.71	Normandy.
	August or September.	.....	.93	5.02	8.24	3.03	Baltic Sea.
	.....	.....	.....	.....	.....	.....	
<i>Laminaria digitata</i> ; broad ribbonweed, broad-leaved kelp, devil's apron, tangle.	January.....	2.26	.58	3.92	2.87	1.68	Rhode Island.
	March.....	2.27	.....	.....	.....	.....	Do.
	September..	1.34	.23	.68	2.57	1.31	Do.
	.....	.....	.48	4.18	2.21	1.39	
<i>Rhodomenia palmata</i> ; dulse, dilfesk.	January.....	3.50	.84	9.95	6.35	.97	Normandy.
	September..	1.92	.53	5.84	.63	.33	
<i>Phyllophora membranifolia</i> .	January.....	3.49	.39	2.28	15.71	2.03	Rhode Island.
	March.....	2.78	.41	2.80	19.20	2.34	Do.
	September..	3.36	.48	3.62	8.99	1.66	Do.
<i>Chondrus crispus</i> ; Irish moss or Carrageen moss.	January.....	2.84	.69	5.11	2.68	1.37	Do.
	March.....	3.10	.57	3.67	1.09	1.49	Do.
	September..	1.32	.40	3.69	2.07	1.37	Do.
	.....	.....	.08	3.57	1.48	2.34	Catagat.
<i>Cladostephus verticillus</i> .	March.....	4.02	.89	5.22	.....	.....	Connecticut.
	January.....	1.57	.78	4.92	3.02	1.25	Rhode Island.
	September..	3.30	.60	1.44	2.40	.72	Do.
<i>Ahnfeldtia plicata</i> .	do.....	1.69	.39	3.50	.88	1.11	Do.

*American, Pacific.*—Balch's analyses<sup>1</sup> of the Pacific kelps are of especial interest. His investigation pertained to the composition of the various parts of the three most conspicuous of the giant kelps—*Pelagophycus*, *Nereocystis luetkeana*, and *Macrocystis pyrifera*. His results are given as follows:

(1) *Pelagophycus porra*. Young plant.

Portions of the bulb (bladder) were allowed to dry, the effloresced salts were shaken off, and the remaining material was charred and lixiviated. The analysis of the lixivate gave:

	Per cent.		Per cent.
K.....	34.91	SO <sub>4</sub> .....	1.33
Na.....	11.74	CO <sub>2</sub> .....	1.01
Cl.....	51.01		

The analysis of the effloresced salts gave:

	Per cent.		Per cent.
K.....	51.993	SO <sub>4</sub> .....	0.097
Cl.....	47.88	CO <sub>2</sub> .....	.030

<sup>1</sup>J. Ind. Eng. Chem., 1, 777 (1909).

The table of results shows that the effloresced salts are practically pure potassium chloride. The specimen as a whole gave 62.67 per cent of alkaline salts, of which 78 per cent was potassium chloride, equaling 48.85 per cent of the original sample. There was about 0.1 per cent iodine present.

The examination of the bladder and apophysis of a mature plant showed the presence of 47.76 per cent potassium chloride. The effloresced salts proved to be 98.72 per cent potassium chloride.

The analysis of the branches of a mature plant—the solid, flattened stems—having petioles and small portions of the tough bases of the leaves still attached, showed crude salts to be present, representing 50 per cent of the weight of the sample.

As we approach the leaves we find the percentage of sulphate augments, and we find iodine also increasing. In the salts of bladder and apophysis, iodine rarely exceeds 0.1 per cent. In the salts from the arms we find 0.328 per cent.

In the leaves was found 28.31 per cent crude salts, of which 49.24 per cent was potassium chloride and 12.27 per cent potassium sulphate (=61.51 per cent potassium salts); iodine, 0.85 per cent.

### (2) *Nereocystis luetkeana*.

The analysis of the effloresced salts from bladder and apophysis, equal to 58.51 per cent of the total weight, showed the combined weight of sodium and potassium therein to be 50.22 per cent, the ratio of sodium to potassium being 1 to 4. Iodine was present slightly exceeding 0.1 per cent. The stem afforded 33.51 per cent salts, of which 0.39 to 0.41 per cent was iodine. The leaves from a young plant gave 44.53 per cent salts, of which potassium salts composed 71 per cent (K=36.55 per cent).

	Per cent.		Per cent.
K .....	36.55	SO <sub>4</sub> .....	5.26
I .....	.117	CO <sub>2</sub> .....	.52
Cl .....	46.52		

### (3) *Macrocystis pyrifera*.

The analysis of the salts (=21.80 per cent) obtained from the leaves of the *Macrocystis* gave the following results:

	Per cent.		Per cent.
Cl .....	40.44	SO <sub>4</sub> .....	11.20
I .....	.70	CO <sub>2</sub> .....	1.08

The stems afforded 29.32 per cent salts.

TABLE XIV.—*Balch's analyses of Macrocystis pyrifera.*

	Old plant, fragmen- tary leaves.	Less ma- ture plant, perfect leaves.
	Per cent.	Per cent.
CO <sub>2</sub> .....	3.96	3.43
SO <sub>4</sub> .....	6.08	12.50
Cl .....	42.12	38.05
I .....	.64	.507
K <sub>2</sub> SO <sub>4</sub> .....	8.79	
K Cl .....	67.76	

J. W. TURRENTINE.



## APPENDIX Q.

### THE TECHNOLOGY OF THE SEAWEED INDUSTRY.

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A discussion of the technology of the seaweed industry logically begins with a consideration of the technology of the propagation of sea plants.

Algae culture in Japan is conducted on a large scale and constitutes an important industry. In Japan, however, seaweeds are valued more on account of their food value; and, as is always the case in growing plants for food, special varieties are especially valued and, consequently, cultivated.

Algae-cultural methods in vogue in Japan are fully described in a paper by Dr. Hugh M. Smith, of the United States Bureau of Fisheries.<sup>1</sup> Such methods can scarcely be applied in connection with the propagation of the kelp weeds for purposes of potash, and for that reason will not be discussed here.

The giant kelps of the Pacific grow in water of comparatively great depth, and in swift tideways or heavy surfs. It follows that they are plants of hardy growth. Those conditions favoring their growth can not be controlled with any readiness by artificial means.

There is one particular, however, in which their propagation can be promoted and that is in constructing a bottom upon which the young plants can find anchorage. The growth of the plant depends on its being able to find a firm anchorage in regions where the other conditions are favorable. For its development a rocky bottom is essential. Kelp groves might be propagated, then, in certain regions now barren of the growth by scattering stones over the sandy bottoms. Before such steps are taken, however, to provide anchorage for the young plants, it should be ascertained whether the condition of the bottom is suitable.

#### HARVESTING.

On the coast of Europe the kelp is gathered from the beach, where it has been washed up by the waves, or is cut by hand from its beds exposed at low tide. In Japan, in addition to the two methods mentioned, the plants are cut from their beds by sickles, fastened to the ends of poles and operated from boats, or are caught in rakes and hooks and are pulled from their anchorage.

Kelp gathering by manual labor is possible in the parts of Europe where that is practiced and in Japan, for manual labor there is cheap. On the Pacific coast, however, the conditions are quite

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<sup>1</sup> Cf. Bulletin, Bureau of Fisheries, for 1904, vol. 24, 133-181.

different. Labor is in demand and is correspondingly high in price. To gather kelp by the piece by hand there is economically impossible. The employment of mechanical harvesters, then, becomes virtually a necessity.

The giant kelps of the Pacific coast grow in water of considerable depth. The chlorophyll-bearing parts require the sunlight in order that they may perform their proper functions. Accordingly, in the case of some of the species, notably the *Nereocystis luetkeana*, of the Puget Sound region, the *Pelagophycus porra* and *Macrocystis pyrifera*, of the southern coast, they are provided with air-filled floats which support the main portions of the plants, the leafy fronds, at or near the surface of the water. The floats are attached to long, cordlike stems, or stipes, which extend to and are firmly attached or anchored upon the bottom. The thick, fleshy parts of the plant, making up the float, and the stems carry the largest proportion of valuable constituents, while the cordlike stem is comparatively lacking in them. While these plants may be growing, then, in 6 to 10 fathoms of water, to harvest them it is only necessary to go to a depth of a few feet; at this depth, also, a large proportion of the sporangia are not destroyed.

A harvester, cutting a few feet below the surface, would, in the case of the first two, sever the floating parts of the plants, comprising by far the larger part, from the stipe.

The cutting of the *Macrocystis pyrifera* would present a somewhat different problem. This plant begins to branch near its anchorage on the bottom; some of its branches do not reach the surface, though they all project in that direction, being supported by numerous small air sacs, or floats. To cut this plant just below the surface would sever the fronds reaching to or floating upon the surface. However, to cut deeper would sever increasing—though probably not proportionately so—amounts of the plants. The amounts being harvested, then, could be greatly increased by increasing the depth of the cutting.

The cut plants doubtless would gather in masses on the surface, and either would be washed ashore or would be dispersed by the wind. Undoubtedly considerable amounts would be lost, and if the weeds were allowed to remain in the water for any great length of time, some of the saline contents would be lost through outward diffusion. If washed ashore, they would be found scattered over a considerable length of beach, where their collection would be attended by no little labor. Furthermore, if they were allowed to dry out there, their salts would be effloresced and lost. It can be seen readily that a much more satisfactory and economical procedure would be both to cut and gather the plants by mechanical devices.

A mechanical cutter is employed at San Diego, Cal., with revolving blades. To avoid the difficulties incident to the entangling of the long fronds of the kelp with any revolving parts it would appear that the adaptation of the sliding cutting bars of the mowing machine would be preferable to revolving knives.

The practice at San Diego is to cut the weeds 10 feet beneath the surface and to let them float ashore. A boat equipped as a harvester for gathering the cut plants could be made to follow closely the boat provided with the cutting apparatus. Or, preferably, one boat could be provided with both the cutting and the gathering apparatus.

A cutting bar 15 or 20 feet long, with all revolving parts encased, could be attached to the side of the boat near its bow and made to project horizontally outward, in a direction at right angles to the long axis of the boat and at any desired depth beneath the surface of the water. Placed behind the cutting bar could be constructed a scooplke rake of converging steel rods for catching the plants as they are severed. The kelp could then be removed by hand; or, better, by rakes attached to traveling chains or by belt conveyors.

The length of the kelp, its toughness, and, when dry, its stiffness, make it highly desirable that it be cut up into short lengths. Thus the handling would be greatly facilitated. It is to be recommended that the kelp be passed, while wet and pliable, through a sort of cutting box and cut into the lengths found desirable. If the cutting box be a part of the harvesting boat's equipment, the kelp could be conveyed directly thereto from the "collector," and from the cutting box into drainage bins. Thus the harvester could be operated until the bins were filled and could then be unloaded at its dock in any suitable manner.

If the boat be unloaded at the lixiviating plant, the weeds could be transferred directly to the drying sheds; if at such a distance that they would have to be shipped thereto by rail, they could be partially cured and then packed into bales for shipment. If retort burners were to be used, it would be found desirable then, also, to compress the kelp into blocks or cakes for charging the retorts. The apparatus here proposed need not be of very great expense. Doubtless it could be built upon a seagoing barge, either provided with its own motive power or designed to be propelled by a tug or other power craft. The different parts would be longer, but should not be much more expensive, than the corresponding parts of the harvester to be found on every modern farm. Power to operate the moving parts could be furnished by a small petrol motor or by the engine operating the propeller.

For packing the kelp into bales the common hay baler of the farm could be employed.

Thus by the method here proposed the kelp may be harvested and delivered at the lixiviating plant mechanically and with a minimum expenditure of manual labor. The apparatus suggested for effecting this may be built simply and cheaply. Its operation and maintenance should be inexpensive. In connection with the latter, however, it should be said that the corrosion by the sea water of the movable parts submerged would make it advisable to have them removable or adjustable, so that they could be lifted above the water when not in operation.

#### CURING.

In Japan, where seaweed is to be used in the preparation of foods, the curing is conducted with some care. The seaweed is laid out in rows on the shore or is hung on lines and poles for bleaching by the sun and dew.

On the European coast the curing consists wholly in drying the plant so that it can be burnt. For this purpose it is merely spread on the shore in the sun. The kelp industry there is confined accordingly to the summer months. In Brittany the kelp is per-

mitted to undergo a preliminary fermentation in heaps, the object of which is not quite apparent.

Such methods of curing are not applicable to the Pacific coast, because of the enormous loss in potassium salts resulting through the dislodgment of the salts effloresced during the drying. If the curing of the plants is to be undertaken by those living along the shore, it must be carried out on platforms with tight floors so that the effloresced salts may be preserved. The drying kelp, it is evident, must be thoroughly protected from showers. When the operation is conducted on a large scale, permanent drying sheds, with tight floors and roofs, might be employed. Balch recommends that they also be inclosed to prevent the finely divided crystals of potassium salts being blown away. He has patented (United States Patent 825953) and recommends the use of drying platforms covered with glass in sloping frames and provided with steam coils beneath the floor to increase the rate of drying.

With furnaces constructed so that full and proper use can be made of the heat evolved during the combustion, it is believed that the necessity for extensive drying sheds can be done away with. This would be a distinct advantage. Not only would a saving be effected in the cost of the initial installation, but if drying were carried to the point where efflorescence took place during the subsequent moving of the kelp the effloresced salts would fall off. Provision would have to be made in both equipment and manipulation for conserving these. The salts thus accumulated, in a highly concentrated condition, might be used directly in fertilizers.

If the salts are to be purified or separated from the organic matter of the kelp plants the latter would have to be subjected to either a winnowing process, which doubtless would not effect a complete separation of the organic and inorganic substances, or a charring process followed by lixiviation. The latter would effect the perfect separation. If this method were adopted, more would be gained, probably, by incinerating and lixiviating the effloresced salts together with the main body of the kelp, thus involving but one operation. However if the burning is conducted in furnaces where the combustion takes place in a current of air, or where the temperature is poorly regulated, the additional potassium salts might increase the difficulties liable to be encountered there, due to the fusion of the salts. This difficulty would not arise if the distillation method of incineration were used.

It may be found advantageous to treat the effloresced salts separately, and even to adopt measures to increase the efflorescence. However, this is doubtful. In such a case the degree of efflorescence could be increased, according to Balch, by checking the rate of drying at the point where efflorescence just begins. The conditions of the membranes of the plant at that stage is described as one favoring a "crude form of dialysis" by which the saline constituents of the plant are dialyzed to the surface. Too rapid drying is supposed to check this. About 40 per cent of the salts may be extracted in this way. However, it may be repeated, the extraction of all the salts in one operation would appear to be more economical, and it is believed that the adoption of measures to prevent, rather than to increase, efflorescence will be found advantageous.

The prevention of efflorescence could be accomplished by charging the kelp into the retorts or other form of incinerators in the moist condition. By an arrangement constructed on or involving the principle of the preheater, perfect drying, even from a pretty wet condition, could be effected and the salts would thus be effloresced only after the kelp had been put into the incinerator.

#### THE BURNING OF KELP.

*Heap burning.*—In the early days of the kelp industry the ashes of sea plants—"kelp," as it was originally called—were obtained in the most primitive manner by burning the plants in heaps or piles. This was the principal industry of the poorer classes of people, crofters and cottars, living near the shore in Scotland. Generally, crude fireplaces were used for the burning, these consisting of shallow depressions in the sand of the shore to catch and retain the resulting ashes. More elaborate fireplaces were constructed at times by surrounding the depressions with low stone walls. Once started, the fires were kept going by the addition of the dried plants. Heap burning was practiced for a century on the coast of the British Isles and of Brittany and is in use to-day on the Scandinavian coast.

The great advantage of the heap-burning method is its extreme simplicity and cheapness, entailing no expense but that represented by the manual labor involved. The latter is a small item, as the curing and burning can be and is carried on to a certain extent by the women and children and in isolated regions where labor has no ready market. It thus furnishes employment and revenue to a class of people in need of both. Finally, its employment makes possible the conversion of a substance, the seaweed, furnished in great quantities by nature, which would otherwise be a total loss, into a product which, though of very inferior quality, yet has some value in the market.

The disadvantages of this method, on the other hand, are so numerous as to render its abandonment imperative. The one of main importance—serious enough alone to condemn the method—is that 50 per cent of the iodine and a smaller but quite considerable proportion of the potassium salts are lost through the volatilization occasioned by the high temperature attained during the combustion. A considerable quantity of sand finds its way into the ash, either accidentally through careless manipulation or intentionally to increase the weight of the ash, and reacts at high temperature with the alkali salts to form silicates; these, subsequently, in the lixiviation and purification processes are liable to decompose with the formation of troublesome compounds. Moreover, sulphates and probably phosphates are reduced, and these two valuable constituents are lost. During the extraction and purification processes sulphur is precipitated through the decomposition of sulphides and introduces complications.

The kelp ash, resulting from this process, is in the form of a hard, fused mass. It is sometimes broken up by pouring cold water on it while hot.

The method of curing occasioned by the shore-burning process is hazardous, as rain falling on the drying kelp washes out most of its saline constituents and thus renders the labors of the harvesters void.

On that account the industry has to be abandoned during the winter months.

In southern California the last-named objection would not apply. However, the practice would entail the loss of practically all the effloresced salts which form so conspicuously on the Pacific kelps, a consideration which makes the method very ill advised.

As a final objection it should be pointed out that in the process of burning kelp on the shore all the organic materials, of possibly very great value in the arts, and of demonstrated value as a fertilizer, are destroyed; and the heat resulting from the combustion, which at best could be used to very great advantage in the evaporation processes subsequently to be performed, is altogether wasted.

Thus useful by-products are lost, a portion of the main products, potash and iodine, is driven off, and the resulting ash is of an inferior quality and is difficult to handle. The practice of burning kelp on the shore in heaps in the open air, then, is extremely wasteful and can not be too strongly discouraged or condemned.

*Distillation.*—In 1862 a vastly improved method of burning kelp was introduced by E. C. C. Stanford, of the North British Chemical Co. (Ltd.), of Glasgow, which depended on the partial burning, or distilling, of the seaweeds in closed retorts and at a temperature not exceeding low redness.

In this process the loss in iodine and potash is probably negligible on account of the low temperature attained. It is estimated that the distillation method yields more iodine by 100 per cent than the heap-burning process. On the completion of the distillation in absence of air a residue of very porous charcoal remains, instead of the hard lumps of fused salts, from which the soluble salts, including all the iodides, may be leached out with readiness. A clear solution results, from which the dissolved salts may be crystallized directly without further purifying.

The products of the distillation consist of ammonia, acetone, and wood spirit, a light volatile oil, a paraffine oil, a coloring matter, tar, and combustible gases. (Stanford.)

The gases may be burnt under the retorts to furnish heat for the distillation (Balch's patent), or under the crystallizing pans for evaporating the lixiviate.

After the lixiviation has been effected a light, porous charcoal remains, resembling animal or bone charcoal, and possessing unique and valuable properties. This may be used as fuel under the retorts or pans in case it can not be put to better uses. Its extreme porosity, however, makes it a very effective deodorant and decolorizer. As the latter, it has been found that it would decolorize 25 per cent more caramel than would an equal weight of animal charcoal. Its high content of lime salts, however, prohibits its employment in the sugar industry. It makes a very effective filter; "it has been subjected to the thickest town sewage for several months without the least clogging, and its efficiency after this treatment remained unimpaired." As a substitute for bone black it has been most highly recommended. Its composition is indicated by the following table, the figures here given representing the average obtained from the analysis of several specimens.

TABLE XV.—*Composition of kelp char.*

[Stanford's analyses of seaweed char.]

	Per cent.		Per cent.
Carbon (free).....	50	Silica.....	5
Calcium phosphate.....	4	Alumina.....	2
Calcium carbonate.....	20	Potassium sulphate.....	5
Magnesium carbonate.....	6	Chlorine-iodine.....	5

The advantages of the Stanford method of burning kelp are self-apparent. The increase in the yield of iodine by 100 per cent and in that of potash by a large proportion are sufficiently great to make its employment in the place of the heap-burning method practically obligatory. Besides, the value of the by-products, the volatile oils, and the charcoal is probably considerable. However, our information concerning the quantities of the former by-products obtainable is as yet quite meager, and a market for such large quantities of charcoal would have to be developed. Yet its employment within the plant as a fuel would always be possible; the ashes resulting from its combustion would then be available in large amounts for those industrial applications for which they are adaptable.

The solution resulting from the lixiviation of the char is clear and colorless. It is a practically uncontaminated solution of the chlorides and sulphates of sodium and potassium, from which it is possible to obtain a precipitation of high-grade salts at a single crystallization. Sulphides are absent. Furthermore, the sulphates and phosphates, the former of actual and the latter of potential value, are unreduced and therefore are not lost.

The employment of the Stanford distillation method at once suggests large, central stations, to which large amounts of the partially dried kelp could be delivered conveniently. This would, in fact, be necessary unless small portable furnaces could be employed for burning the kelp when it is thrown upon the shore.

Mr. David M. Balch, of Coronado, Cal., has been granted a patent (United States patent 747,291) covering a process for distilling kelp in a closed retort. His experiments<sup>1</sup> are of especial interest as they have to do with the giant Pacific kelps.

The plants are thoroughly sun dried, are broken up and are lightly compressed in the retort. Lime, or other alkaline substance, is sprinkled over the kelp in the proportion of about 40 grams per kilogram of dried seaweed. The material is then subjected to heating—

the degree of heat being sufficiently high to completely decompose the organic portion of the seaweed, but not high enough to break up the sulphates present.

The retorts or chambers are connected with suitable condensing appliances and to receivers, and all condensible volatile products arising from this modified form of dry distillation, together with the uncondensable gases generated, are collected apart. The heating of the retorts or chambers is maintained until no further volatile products are evolved.

This method of distillation, it will be observed, has many points in common with the Stanford method.

The char is lixiviated and a light, porous charcoal remains behind. From a single crystallization of the lixivate a beautiful product of potassium chloride is obtained directly, commercially pure.

<sup>1</sup> Jour. Ind. Eng. Chem., 1, 777 (1909).

The alkaline substances added to the kelp before distillation, it is claimed—

favor the complete separation of the soluble from the insoluble mineral salts of the particular kelp under treatment and is of decided advantage in breaking up and converting into ammonia certain difficultly decomposable nitrogenous constituents.

Portable furnaces, of sheet iron, could be constructed on the Stanford or Balch plan, with closed retort. The latter, if mounted on a swivel, could be dumped without coaling. A petroleum burner could be used for starting, or assisting in, the distillation, though the main fuel employed would be the combustible gases evolved during the distillation and led back under the retort for combustion. The construction of the furnace could be light and compact; it could be mounted on a truck for draft by horse. However, its expense probably would be too great for the ordinary individual living along shore. It might be found feasible for the operation of lixiviating plants to lease portable burners in accordance with some cooperative scheme.

Retort furnaces for the distillation of seaweed could probably be built and operated most advantageously after the manner of coke ovens. Thus the retorts could be built in series with the regenerative and condensation features of the modern coke ovens. With a proper construction only partially dried kelp would be charged and the operation would then be practically a continuous one.

The construction of a furnace is suggested in which kelp could be charred by a strictly continuous process. The furnace should be of the closed muffle type, with sloping muffle; the top part of the nature of a preheater and provided with a charging bell, to prevent the escape of gases, and the bottom part a regenerative cooler, provided with a tightly fitting, sliding door, to permit the removal of the char. The gases, if led from the top part of the furnace, could be made to pass through the charge in the cooler portion of the furnace; or they could be led out at any desirable point. After passing through a condenser for the recovery of the condensible constituents, they could be burnt within the furnace, under the muffle. Any such furnace, however, would have to be operated with sufficient care to prevent the temperature within the muffle from reaching a point at which the char would begin to cake. Caking would be caused by the fusion of the potassium salts within the char. The movement of the charge through the furnace would tend to obviate that danger.

The proper construction of the preheater makes possible the use of kelp only partially dried; thus would the drying and charring, or distilling, be carried out in stages of one operation, and the effloresced salts would be liberated within the furnace.

De Roussen has patented<sup>1</sup> a method of distilling seaweed, the salient points of which are given as follows:

The seaweed is bruised and is treated with some astringent to render the nitrogenous parts insoluble. It is then sprinkled with a weak solution of soda lye (5°–10° B.) and is allowed to drain. The plants are now introduced into the coolest part of a furnace, which is heated externally, and, by means of some suitable mechanical device, are gradually brought forward to the hottest part, where they

<sup>1</sup> English patent 4214 (1882?).



lose their "volatilisable and pyrogenous products." The carbonization is complete when smoke ceases to escape from the chimney. The char is cooled, sifted, the lumps broken up, and is then lixiviated. The charcoal is dried and is used for fuel. "The gaseous products escaping from the retort are condensed and separated in the usual way."

*Lixiviation without burning.*—For a century the Japanese have prepared large quantities of numerous products from seaweed which have found a wide use as foods and constituents of foods, and in the arts and sciences. They have devoted their attention to the organic rather than to the inorganic constituents of the sea plants, though it is stated that they are producing iodine from seaweed of an annual value of \$130,000.

The constituents of kelp which possess a food value probably partake of the nature of complex carbohydrates. For a discussion of this important industry of Japan, see the interesting Separate from the Bulletin of the Bureau of Fisheries for 1904, volume 24, pages 133–181, by Dr. Hugh M. Smith, and Appendices K and R of this report.

Stanford investigated the kelps of the British Isles and found that they contained substances other than the inorganic constituents, for which alone the kelp up to that time had been valued, of such a wide range of applicability that he compared the destructive distillation of kelp for the recovery of iodine to the similar destruction of mahogany or of other precious woods for the preparation of lye or distillation products. While the distillation of wood can be carried on with profit, it is manifestly absurd to subject it to destructive distillation if it can be marketed for more than its distillation products will bring.

Stanford devised a method of treating kelp whereby not only all of the valuable inorganic constituents can be removed, but also the organic parts can be recovered and subsequently be applied to any use for which they are adapted. This method depends on the lixiviation of the dead plants.

While the living plant is able to take into its tissues certain inorganic substances through selective absorption, the dead plant, it has been shown, is unable to retain them. The rate at which these are removed by fresh water and the order in which the various inorganic salts are given off has been studied by Stanford.<sup>1</sup> He recommends simple maceration in cold water, "the salts being almost entirely removed even by two macerations." The resulting solution contains about one-third of the weight of the dried plant, representing the soluble inorganic salts and certain organic substances of the nature of sugar, mannite, etc.

The separation of the saccharine from the saline substances presents some difficulties which will not be overcome until the economic value of the sugars has been investigated. In the meantime, the sugars are sacrificed by incinerating. The salts are then separated in a satisfactory condition by lixiviation.

<sup>1</sup> Chem. News, 47, 254–267 (1883).

The following table (Table XVI) represents the composition of the salts obtained from two varieties of sea plants by maceration in water:

TABLE XVI.—*Composition of saline matter dissolved from two varieties of kelp by lixiviation.*

Constituent.	1. <i>Laminaria stenophylla</i> .	2. <i>Fucus vesiculosus</i> .
	<i>Per cent.</i>	<i>Per cent.</i>
Calcium sulphate.....	1.69	4.33
Potassium sulphate.....	11.29	23.62
Potassium chloride.....	19.90	13.71
Sodium chloride.....	60.96	58.20
Magnesium chloride.....	4.35	.....
Sodium carbonate.....	.53	.....
Sodium iodide.....	1.26	.12
Total.....	99.98	99.98

In the following tables the composition of the salts are shown as obtained in six successive macerations in cold water.

In each case solutions resulting from the macerations were evaporated to dryness, the solid residue was carbonized, washed, again ignited, and again washed. This treatment insured the complete separation of the saline constituents from the organic.

TABLE XVII.—*Amounts of salts obtained by successive lixiviations of Laminaria stenophylla, air dried.*

[Moisture, 14.8 per cent; sample of 4 ounces=1,750 grains; 6 macerations.]

Maceration.	Weight residuum (grains).	Per cent.	Grains.	Per cent.
First maceration.....	288.0	16.45	499	28.5
Second maceration.....	211.0	12.05		
Third maceration.....	40.0	2.28		
Fourth maceration.....	37.2	2.12		
Fifth maceration.....	21.1	1.20		
Sixth maceration.....	18.6	1.06		
	615.9	35.16	39.7	2.26

Table XVIII shows the proportions of the organic and inorganic constituents of the lixivate.

TABLE XVIII.—*Composition of matter dissolved by successive lixiviations.*

Maceration.	Volatile matter.	Salts.	Fixed carbon.	Ash.	Total.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	23.4	67.1	3.91	5.59	100.0
Second maceration.....	28.0	60.1	4.97	6.93	100.0
Third maceration.....	29.3	55.5	4.1	11.1	100.0
Fourth maceration.....	40.0	40.0	4.56	15.44	100.0
Fifth maceration.....	54.5	31.8	2.23	11.4	100.0
Sixth maceration.....	60.1	22.5	.96	7.44	100.0

In Table XIX is given the composition of the salts obtained in the six successive lixiviations of the raw plant:

TABLE XIX.—Composition of salts dissolved in the successive lixiviations.

Maceration.	Calcium sulphate.	Potassium sulphate.	Potassium chloride.	Sodium chloride.	Sodium iodide.	Sodium carbonate.	Magnesium chloride.	Total.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	2.91	7.53	34.06	45.55	1.95	Nil.	8.55	100.54
Second maceration....	1.02	10.08	30.95	53.00	1.58	Nil.	3.40	100.03
Third maceration.....	Nil.	19.48	24.81	53.57	2.00	Trace.	Trace.	99.86
Fourth maceration....	Nil.	20.80	23.78	51.04	1.25	3.30	Trace.	100.17
Fifth maceration.....	Nil.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	.....
Sixth maceration.....	Nil.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	.....

TABLE XX.—Values from Table XVIII calculated to per cent of original weight of material lixiviated. *Laminaria stenophylla* (air dried).

Maceration.	Total soluble.	Volatile.	Salts.	Carbon.	Ash.
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
First maceration.....	16.45	3.85	11.04	0.64	0.92
Second maceration.....	12.05	3.35	7.26	.60	.81
Third maceration.....	2.28	.68	1.26	.09	.25
Fourth maceration.....	2.12	.86	.85	.09	.32
Fifth maceration.....	1.20	.656	.38	.027	.137
Sixth maceration.....	1.06	.73	.24	.01	.078
Total.....	35.16	10.13	21.03	1.46	2.54

TABLE XXI.—Composition of salts, calculated on basis of original weight.

Maceration.	Calcium sulphate.	Potassium sulphate.	Potassium chloride.	Sodium chloride.	Sodium iodide.	Sodium carbonate.	Magnesium chloride.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	0.321	0.83	3.76	4.97	0.22	Nil.	0.94
Second maceration.....	.07	.73	2.25	3.85	.11	Nil.	.25
Third maceration.....	Nil.	.25	.31	.68	.03	Trace.	Trace.
Fourth maceration.....	Nil.	.18	.20	.43	.01	0.03	Trace.
Fifth maceration.....	Nil.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
Sixth maceration.....	Nil.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.

TABLE XXII.—Proportions and composition of the products of lixiviation. *Laminaria stenophylla* (air dried).

#### UNDISSOLVED MATTER.

[Two ounces equal 50 per cent original weight.]

Constituent.	Composition.	Original weight.
	<i>Per cent.</i>	<i>Per cent.</i>
Volatile matter.....	74.2	37.1
Charcoal.....	25.8	12.9
Total.....	100.0	50.0

#### CHARCOAL.

Salts.....	18.0	2.32
Fixed carbon.....	50.7	6.55
Ash.....	31.3	4.03
Total.....	100.0	12.90

TABLE XXII.—Proportions and composition of the products of lixivation. *Laminaria stenophylla* (air dried)—Continued.

## SALTS.

[Two ounces equal 50 per cent original weight.]

Constituent.	Composition.	Original weight.
	<i>Per cent.</i>	<i>Per cent.</i>
Potassium sulphate.....	35.27	0.82
Potassium chloride.....	6.72	.16
Potassium carbonate.....	5.00	.12
Sodium carbonate.....	49.97	.17
Sodium iodide.....	2.63	.06
Alkaline earths.....	Nil.	Nil.
Total.....	99.49	2.32

TABLE XXIII.—Amounts of salts obtained by successive lixivations of *Fucus vesiculosus*—dried.

[Moisture, 2.11 per cent; sample o. 4 ounces equals 1,750 grains; 6 macerations.]

Maceration.	Weight residue.	Per cent.
	<i>Grains.</i>	
First maceration.....	174.5	9.45
Second maceration.....	43.0	2.45
Third maceration.....	11.2	
Fourth maceration.....	6.15	.99
Fifth maceration.....	Trace.	
Sixth maceration.....	Trace.	
Total.....	234.85	12.89

TABLE XXIV.—Composition of matter dissolved by successive lixivations.

Maceration.	Volatile matter.	Salts.	Fixed carbon.	Ash.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	37.78	49.03	8.09	5.10
Second maceration.....	68.4	27.62	1.17	2.81
Third maceration.....	47.48	29.22	3.78	19.52
Fourth maceration.....	62.86	25.71	.74	10.69

TABLE XXV.—Composition of salts dissolved in the successive lixivations.

Maceration.	Potassium sulphate.	Sodium sulphate.	Sodium chloride.	Sodium iodide.	Sodium carbonate.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	27.25	4.04	61.50	0.03	7.42
Second maceration.....	48.19	.57	37.62	.02	13.36
Third maceration.....	Trace.	Trace.	Trace.	Trace.	Trace.
Fourth maceration.....	Trace.	Trace.	Trace.	Trace.	Trace.

TABLE XXVI.—Values from Table XXIV calculated to per cent of original weight of material lixivated. *Fucus vesiculosus* (dried).

Maceration.	Per cent.	Volatile.	Salts.	Carbon.	Ash.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	9.45	3.58	4.63	0.76	0.48
Second maceration.....	2.45	1.68	.67	.03	.07
Third maceration.....	.64	.30	.19	.02	.13
Fourth maceration.....	.35	.22	.09	.003	.04
Total.....	12.89	5.79	5.58	.82	.71

TABLE XXVII.—*Composition of salts calculated on basis of original weight.*

Maceration.	Potassium sulphate.	Sodium sulphate.	Sodium chloride.	Sodium iodide.	Sodium carbonate.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
First maceration.....	1.26	0.19	2.84	0.001	0.34
Second maceration.....	.34	.004	.23	.0001	.09
Third maceration.....	Trace.	Trace.	Trace.	Trace.	Trace.
Fourth maceration.....	Trace.	Trace.	Trace.	Trace.	Trace.

TABLE XXVIII.—*Proportions and composition of the products of lixiviation.*  
UNDISSOLVED MATTER.

[Weight, 3 ounces; 175 grains equals 85 per cent.]

Constituent.	Composition.	Original weight.
	<i>Per cent.</i>	<i>Per cent.</i>
Volatile matter.....	65.65	65.81
Charcoal.....	34.35	29.19
Total.....	100.00	85.00

## CHARCOAL.

Salts.....	18.63	5.24
Fixed carbon.....	58.53	17.53
Ash.....	22.84	6.42
Total.....	100.00	29.19

## SALTS.

Potassium sulphate.....	29.41	1.54
Sodium sulphate.....	47.53	2.50
Calcium sulphate.....	9.34	.48
Magnesium sulphate.....	11.76	.62
Magnesium chloride.....	1.30	.068
Sodium carbonate.....	.45	.024
Sodium iodide.....	.22	.012
Total.....	100.06	5.24

These tables afford a good idea of what may be expected of a direct lixiviation process. A discussion of the mechanical details involved in such an operation need not be entered into here, though the actual application of the process doubtless would not present very serious difficulties. Suffice it to say that the lixiviation could be effected by the method of countercurrents, from which a solution saturated with respect to the inorganic constituents would result. An additional expense involved would be evaporation of this lixivate to dryness, followed by an ignition, to effect the charring of the organic constituents dissolved from the plants with the salts.

The success of the direct lixiviation method would depend on the successful utilization of the organic matter remaining, the conservation of which is the purpose of the method.

Stanford has shown that many varieties of kelp contain large quantities of a weak organic acid which, from its source, he has named "alginic" acid. This material in its free state—*i. e.*, uncombined with a base—is insoluble in water and in dilute acids. It unites readily with numerous bases to form with some of them soluble salts and with others insoluble salts of striking characteristics. The soluble salts are gums of great viscosity; the sodium alginate in 2 per cent solution excels in viscosity gum arabic in 50 per cent solution. A 5 per cent solution is so viscous that it can scarcely be poured.

The treatment of the kelp for the extraction of its valuable constituents consists, then, in a maceration with water, repeated once or twice, to remove the soluble salts—potassium and sodium chlorides, sulphates, and iodides. The insoluble residue contains the algin, cellulose, and the insoluble inorganic constituents. This is treated for 24 hours with about one-tenth of its weight of sodium carbonate in solution. The mixture is then heated and filtered. The algin, or alginic acid, reacts with the sodium carbonate to form the soluble sodium alginate and leaves a residue of cellulose or cellulose-like material. The solution is now acidified with sulphuric acid for the precipitation of the algin. This is filtered out as a light-brown precipitate. The filtrate, containing sodium sulphate, is evaporated and from it Glauber's salt is crystallized.

An alternative method of procedure is to omit the preliminary maceration for the removal of the potash. This, then, remains in solution, together with the iodine, and is to be found in the mother liquors from the sodium-sulphate precipitation. The former operation is represented schematically below.

The following comparison of the three processes—the heap-burning, the distillation, and the lixiviation—is taken from the article by Watson Smith.<sup>1</sup>

#### *Heap burning.*

[Per cent utilized—18.]

Ash, 18 tons {Salts, 9 tons } Residuals, waste (valueless).  
                   {Iodine, 270 lbs. }

#### *Distillation.*

[Per cent utilized, 36.]

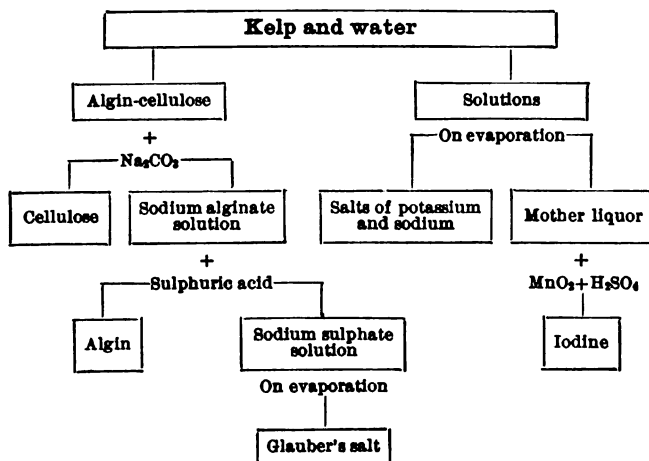
Charcoal, 36 tons {Salts, 15 tons. } Residuals: Charcoal (21 tons), tar, and ammonia.  
                       {Iodine, 600 pounds. }

#### *Lixiviation.*

[Per cent utilized, 70.]

Water extract, 33 tons {Salts, 15 tons. } Residuals: Algin (20 tons), cellulose (15 tons), dextrin, etc.  
                           {Iodine, 600 pounds. }

*The lixiviation process schematically represented.*



<sup>1</sup>J. Soc. Chem. Ind., 4, 518 (1885).

The cellulose remaining after the removal of the algin is recommended for use in the manufacture of paper. It is practically fiberless. When used in combination with other materials which furnish the requisite amount of fiber it can be made into paper of a grade which is said to be excellent.

Krefting, of Christiana, Norway, has introduced numerous modifications into the methods and apparatus for extracting the organic constituents of kelp and for separating the organic and the inorganic ones.

By treating the seaweed in the beginning with dilute sulphuric acid (1 to 6 per cent), and following this with the treatment with alkali or alkali carbonate, a sodium alginate or "tangate" is obtained which, on acidification, yields a product free from nitrogen (English patent 11,538, May 27, 1896).

An interesting product is obtained (English patent 8,042, April 17, 1899) when the alkaline alginates or "tangates" are intimately mixed with the plant fibers, and the resulting mass is dried on moving belts. The addition of various substances, such as dyestuffs, mineral matter, drying oils, soaps, glycerin, glucose, etc., give the product various desirable properties.

For other modifications by Krefting, see English patents 12,275, 12,277, 12,416, 13,151, and 13,289 of the year 1898.

A process for preserving kelp and extracting therefrom the organic jellies has been patented by Pitt (English patent 20,356, 1898). The preservative employed is "heavy gas oils," by means of which accumulations of kelp are preserved for future use, thus rendering the manufacturer independent of a daily supply.

For extraction of the gelatinous matter, the kelp is macerated in water and acidified with sulphuric acid. It is then steamed at a pressure of two to four atmospheres and is filtered, the matter to be extracted from the cellulose being thus separated. Liquors resulting contain the saline matter and are treated for iodine. The gelatinous matter thus obtained is used for waterproofing fabrics, paper, leather, wood, and like materials.

#### PREPARATION OF POTASSIUM SALTS AND IODINE.

In the early days of the kelp industry, and up to the time of its decline, the ash of the seaweed, the original kelp, was prepared, by methods which have been described, on the shores, and was then shipped to the kelp-lixiviating plants. The latter were situated at and near Glasgow, which has always been the center of the kelp industry.

The method of lixiviation of the ash, as it was practiced during the height of the industry, has been described by Stanford.<sup>1</sup> The kelp ash was broken up into pieces the size of road metal and was lixiviated in vats, coupled together and heated by steam. The solution resulting was run off when it had reached a density of 40° to 45° Twaddell. This was evaporated in ordinary open evaporating pans, about 9 feet in diameter. The salts, as they deposited, were raked out.

The crystallization took place in stages, or by fractions. At about 62° Twaddell a rough salt was deposited, consisting of 50 to 60 per

<sup>1</sup> Chem. News, 35, 172, 1877.

cent potassium sulphate, combined with sodium sulphate and chloride. The mother liquor from this crop of crystals was run into cast-iron cooling pans, where, during a period of about three days, potassium chloride crystallized out. This alternate evaporation and chilling was repeated about three times, when ashes of good quality were employed. The successive crops of potassium chloride would range between 80 and 95 per cent KCl. The final mother liquor, 85° to 95° Twaddell, was mixed with about one-seventh of its volume of sulphuric acid of 145° Twaddell and the resulting mixture was allowed to settle. Sulphides and other sulphur compounds were decomposed with the precipitation of sulphur. The liquid was then distilled with manganese dioxide in iron stills. These were provided with lead covers carrying two arms, each of which was connected with a series of stoneware udells. These were for the condensation of the iodine, which separated in them in hard masses. After the iodine had ceased to come off, more manganese dioxide was added and the distillation was continued to remove the bromine then liberated. This was condensed in a suitable apparatus of lead or earthenware, which replaced the udells.

The products obtained, then, in this process were iodine, bromine; "muriate," containing 80 to 98 per cent KCl; "soft sulphate," containing 50 to 65 per cent  $K_2SO_4$ ; "kelp salt," containing sodium chloride and 5 to 10 per cent alkali (free?); "kelp waste," containing mostly calcium carbonate and silica (and doubtless the insoluble calcium phosphate), formerly used in the glass industry, but of doubtful value; and "sulphur waste," containing, when dry, about 70 per cent sulphur. Each solid, upon its removal from the mother liquor, had to be drained thoroughly or else washed to remove the liquor, rich in iodine, which it contained. This tended further to complicate the process.

The process of lixiviation and crystallization as here described is the one which was in general use during the height of the iodine-from-kelp industry. Because of the decline in the industry, the method has not undergone any great modifications.

Lauray<sup>1</sup> has introduced the method of precipitating most of the potassium salts from the mother liquor by saturating the latter with hydrochloric acid. He then adds nitrous and hyponitrous acids, which liberate the iodine but not the bromine.

Stephanelli and Doveri liberate the iodine by evaporating the mother liquor to dryness and by heating the resulting solid mass with manganese dioxide, thus obviating the use of sulphuric acid.

Chlorine, in the form of a gas, or in combination as a hypochlorite (bleaching powder), is also employed for the liberation of the iodine. Its use must be attended with care, however, to avoid the oxidation of the iodine to forms in which it again becomes soluble. Where chlorine and the lower oxides of nitrogen are employed the crude iodine thus precipitated may be filtered from the solution, if the latter is sufficiently concentrated, instead of distilled.

The separation of potassium salts from the lixivate obtained from the char after the distillation, rather than the burning, of the kelp, is a much simpler process than that described. This has been demonstrated amply by the work of Stanford and of Balch. The lix-

<sup>1</sup> *Moniteur Sci.*, 1868, 1042.



lixivate obtained from this material is essentially a solution of the chlorides and sulphates of sodium and potassium, with potassium chloride in the preponderating amount. The experiments performed in the Bureau of Soils, while not exhaustive, indicate that this lixivate is practically free from calcium and magnesium salts.

On evaporation of the lixivate, the solids which would separate will be determined by the relative amounts of the various salts present. If it be assumed, which is usually the case, that the potassium chloride is in excess of any or all the other salts, potassium chloride will at first separate alone as a pure salt. How long this process will continue is determined by the ratios and amounts of the other salts present. Sodium sulphate, glaserite (a double sulphate of sodium and potassium), sodium chloride, or still other salts may be mixed with the potassium chloride, and it is impracticable to predict what will happen or what procedure would be best, without a definite knowledge of the analytical data for the particular lixivate. This point requires further laboratory investigation.

Practicable methods for the approximately quantitative separation of sodium and potassium by fractional crystallization have not been worked out satisfactorily. Preliminary experiments, as the beginning of a research on that problem, have been performed in this laboratory, and it is expected that the investigation will be carried to completion.

The separation of potassium salts following the lixiviation of kelp char is a simpler process than that following the lixiviation from kelp ashes—the solution is freer from impurities and the steps in the operations are fewer and simpler.

The liberation of iodine from the iodides accumulating in the mother liquor can be accomplished by one of several well-known methods.

Stevens (English patent 15,809, Aug. 22, 1895) has introduced the modification in the treatment of the lixivate from kelp of separating the sodium and potassium salts from the first lixivate in the usual way, and the iodine and bromine from the resultant mother liquor by means of manganese dioxide and sulphuric acid, and from the second and subsequent lixiviations by purifying and crystallizing to obtain potassium sulphate and then electrolyzing the mother liquor, containing chlorides, bromides, and iodides, to form chlorates, bromates, and iodates. From this solution chlorates are obtained by crystallization, and the process is repeated, or is carried on in accordance with other schemes, until a solution finally results so concentrated in bromates and iodates that it can be treated successfully for the recovery of bromine and iodine.

Reduction to bromides and iodides is effected by sulphurous acid.

#### DIRECT USE AS A FERTILIZER.

One other alternative method of utilizing marine algae as a source of potash for agricultural purposes lies in their use directly as a fertilizer. In the British Isles they have been so used for centuries.

The dry plants are quite brittle and may be ground to an extremely fine powder with facility. In this form they may be applied to the soil in the same way as are other fertilizers. While they would be considered mainly as a potash fertilizer, and would be mixed with

other fertilizer ingredients as a carrier of potash, if used alone they would represent in a way a complete fertilizer, as they carry, in addition to their very high potash content, both nitrogen and phosphates. In addition to these three there are also certain amounts of carbonate of lime and chloride of sodium, the first generally and the second sometimes regarded as beneficial when added to the soil. There is, furthermore, the large amount of organic matter, representing about 50 per cent of the entire weight, of a sort that undergoes very ready decomposition within the soil. This organic matter swells up enormously when wetted, a quality of advantage in retaining the moisture of the soil within the immediate neighborhood of the root zone of the growing plant. Following is given a comparison of the dried kelp with cottonseed meal and tobacco stems, both of which are considered of high value as fertilizers:

Substances compared.	Moisture.	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Cottonseed meal .....	.....	7.5	2.5	1.5
Tobacco stems .....	10.6	2.3	0.6	6.4
Kelp .....	Trace.	1.5	5.0	23.4

The phosphoric acid content of the kelp given here is somewhat doubtful, as but few analyses of the Pacific kelps have included so far the determination of that ingredient. The value of 5 per cent is taken from published analyses of certain Japanese algae. It is regarded as a very conservative estimate for the Pacific kelps.

In Table XXIX is given a comparison between the average analyses for certain varieties of seaweeds, eelgrass, *Fucus sassates*, from New Haven Harbor, containing 0.94 per cent of potash; seaweed, or kelp, *Laminaria saccharina*, "kelpweed" from Maine, containing 2.46 per cent of potash; and "kelp-fertilizer," *Fucus nodosus*, or "rockweed," containing 2.18 per cent potash—and stable manure.

TABLE XXIX.—The manurial value of kelp, compared with stable manure.

[From Johnson, "Seaweed as fertilizer," Am. Chemist, 2, 297 (1871-72).]

Ingredient.	Parts in stable manure.	Parts in kelp.
Organic matter .....	1	5.0-6.5
N .....	1	2.0-3.0
P <sub>2</sub> O <sub>5</sub> .....	1	1.0-2.5
H <sub>2</sub> SO <sub>4</sub> .....	1	23.0-25.0
NaCl .....	1	37.0-54.0
Soda .....	1	23.0-31.0
Potash .....	1	3.0-4.0
Lime .....	1	2.0-2.5
Magnesia .....	1	1.0-6.0

#### ALGINIC ACID AND DERIVATIVES.

Alginic acid, or "algin," is an organic acid which occurs in large quantities in certain seaweeds. When the plant is macerated with a dilute solution of sodium carbonate, or of other alkaline substances, the alginic acid, by uniting with the base to form a soluble salt, goes into solution. Upon acidifying the solution, the free acid

is liberated, and being insoluble in water, it precipitates as a light-brown, gelatinous mass. On resolution and reprecipitation it is much whitened and may become quite white if the process is repeated a sufficient number of times. When first precipitated it contains about 98 per cent water. In this form it may be filtered and washed, though the large amount of water which it absorbs carries with it parts of the substances dissolved in it. Stanford regarded it as a definite compound and on the basis of his analysis assigned the empirical formula,  $C_{76}H_{80}N_2O_{22}$ . In structure it is regarded as a diamid.

Upon drying algin assumes a hard, hornlike form and has a specific gravity of 1.534. It can be turned on a lathe, or, if pressed into molds while wet, on drying it retains the form thus imparted. Articles constructed of it may be polished, or, if allowed to dry in sheets, the product has properties which make it a substitute for rubber or parchment for certain purposes.

*Derivatives.*—With ammonia, the alkali metals, and magnesium, alginic acid unites to form soluble compounds. Sodium alginate—a typical, soluble alginate—is a gum which has 14 times the viscosity of starch and 37 times that of gum arabic. In solutions it is precipitated by the ions of those metals with which it forms insoluble salts, and by alcohol, acetone, and collodion, but not by ether, and by mineral acids. It is not precipitated by alkalies, starch, glycerol, or cane sugar. It is distinguished from albumen, which it most nearly resembles, by not being coagulated by heat, and from gelose by not gelatinizing on cooling, by containing nitrogen, by dissolving in weak alkaline solution, and by being insoluble in boiling water. From gelatin it is distinguished by giving no reaction with tannin; from starch, by giving no color reaction with iodine; from dextrin, gum arabic, tragacanth, and pectin, by its insolubility in dilute mineral acids and in dilute alcohol.

The proposed commercial applications of alginates are numerous. For sizing fabrics it is especially recommended.

As a finish, algin has the advantage over starch that it fills the cloth better, is tougher, and more elastic, that it is transparent when dry and that it is not acted on by acids. It imparts to the goods a thick, clothly, elastic feeling, without the stiffness imparted by starch. It has the advantage possessed by no other gum of becoming insoluble in presence of a dilute acid, which decomposes starch or dextrin.

Being exceedingly viscous, its solutions have a great covering power.

Sodium alginate is broken down by mineral acids with the precipitation of the insoluble alginic acid. Fabrics, then, which have been dressed with the sodium alginate, when treated with solutions of mineral acids have the algin formed on them in situ. Or, instead of a solution of an acid, one of a compound giving an ion which will form an insoluble compound can be used. Thus, lime-water will produce a precipitate of insoluble calcium alginate within the fibers of the fabric.

*As a mordant.*—Sodium alginate has been found of service as a vegetable mordant, or for precipitating such mordants as those containing iron and aluminum upon cotton fiber.

*As a food.*—But little is known of the edibility of the free acid or of its compounds, though it has been suggested as an article of diet, if not for man, in its cruder forms, at least for beast. Its nitrogen content is about equal to that of Dutch cheese; its composition is: Carbon, 44.39 per cent; hydrogen, 5.47 per cent; oxygen, 46.57 per cent; nitrogen, 3.77 per cent. If calculated to protein, the nitrogen would represent about 23 per cent protein.

For thickening soups and puddings, as a substitute for gum arabic in the manufacture of jujubes and lozenges, in making jellies, it is said that it would be very serviceable.

*In pharmacy.*—As an emulsifier of oils and as an excipient for pills its use has been suggested in pharmacy.

*For softening water.*—Calcium alginate is insoluble in water and may be precipitated from a solution of the sodium salt. Sodium alginate, then, has been found to be an effective "softener" for boiler waters by precipitating therefrom the lime. The resulting precipitate is finely divided and may be "blown off" easily.

*As a binding material.*—Algin in its soluble form should find a wide use as an agglutinizor in the briquetting of the various pulverulent substances in use in the industries, such as silica, lime, magnesia, chalk, zinc oxide, lead oxide, alumina, graphite, carbon, charcoal, etc. When mixed with charcoal a paste results which is spoken of as an excellent black, odorless, and nonconducting coating for boilers and other metal work.

*With shellac.*—The alkaline alginates in water solution have the power of dissolving shellacs. Upon evaporation, a tough, tenacious residue is obtained, soluble in water. On being treated with an acid, the film is rendered insoluble in water, but its other properties, highly desirable in a varnish, remain unimpaired. This resembles gutta-percha, and is said to be a good electrical insulator.

*Compounds.*—Alginic acid forms, with the metallic ions, three series of compounds: (1) With ammonia, the alkali metals, and magnesium, soluble salts; (2) with most of the other metals, insoluble salts; most of these react with ammonia to form (3) a series of very soluble compounds, probably double ammonium salts. Series 3 possesses the remarkable property of becoming insoluble upon evaporation to dryness. From their solutions there separates out, thus, insoluble, water-proof varnishes. In the list which follows of the various alginates and their properties, the characteristics of the final product of class (3) are given.

(1) Water soluble:

Ammonium alginate.  
Sodium alginate.  
Potassium alginate.  
Magnesium alginate.

(2) Water insoluble:

Barium alginate, dense, white.  
Strontium alginate, white.  
Calcium alginate, white, hardening into solid white blocks which take a good polish; forms transparent sheets; specific gravity, 1.6, approaching that of ivory, 1.82.  
Lead alginate, transparent, colorless.  
Silver alginate, colorless, gelatinous; imperfectly insoluble. Easily soluble in ammonia; very sensitive to light.  
Mercury alginate (only mercurous), dense, white, gelatinous; blackened by ammonia.

## (2) Water insoluble—Continued.

Copper alginate, green, gelatinous.  
 Cadmium alginate, colorless, gelatinous.  
 Bismuth alginate, dense, white.  
 Iron (ferric) alginate, reddish, brown. No reaction with ferrous, but quantitative precipitation of ferric.  
 Cobalt alginate, light red, gelatinous.  
 Nickel alginate, light green.  
 Manganese alginate, colorless, gelatinous.  
 Zinc alginate, colorless, gelatinous.  
 Chromium alginate, blue, gelatinous.  
 Aluminium alginate, white, gelatinous; soluble in caustic soda, evaporating to a film.  
 Arsenic alginate, colorless, gelatinous.  
 Antimony alginate, dense, white.  
 Stannic alginate, colorless, gelatinous.  
 Stannous alginate, colorless, gelatinous.  
 Uranium alginate, yellowish brown, gelatinous.  
 Platinum alginate, brown, gelatinous.

## (3) Soluble in ammonia, giving, on evaporation, water-insoluble films:

Silver alginate, dark, reddish-brown film, which on exposure to light becomes a brilliant silver mirror; of possible use in photography.  
 Copper alginate, deep blue solution, bright-green film. Suggested use: Varnish for waterproofing fabrics, etc., liable to decomposition or to attacks of insects.  
 Cadmium alginate, opaque, white film.  
 Ferric alginate, deep-red solution; dark-red film. Suggested use: As a styptic for wounds; in medicine, as a form for administering iron internally.  
 Cobalt alginate, bright-red solution; dark-red film.  
 Nickel alginate, beautiful blue solution; brilliant green film.  
 Chromium alginate, blue solution; brilliant olive-green film.  
 Manganese alginate, brown solution; olive-brown film.  
 Zinc alginate, brilliant, transparent film. Suggested use: Same as that for corresponding copper compound, where color of other is objectionable.  
 Tin (stannous) alginate, transparent film. (Stannic tin, transparent film, soluble in water.)  
 Uranium alginate, deep yellow solution; brilliant yellow film.  
 Platinum alginate, yellow solution; yellow film.

Experiments of a preliminary character performed in this laboratory with specimens of the *Macrocystis* indicate that this plant is as rich in alginic acid as the *Laminaria*. A small quantity of the weed when treated in the cold with a dilute solution of sodium carbonate formed a solution so viscous that it could scarcely be poured from the bottle in which it was prepared. A portion of this solution, upon acidification, yielded a brown, flocculent precipitate which on drying gave a tough, transparent, horny substance, superficially identical with the algin described by Stanford. It would appear that among so many compounds of unique properties obtainable from the organic constituents of the marine algae, some, at least, would be found of sufficient usefulness in the arts to make their preparation the basis of an industry. However, their discovery was announced 30 years ago and as yet they are not being manufactured, it is believed, to any great extent. The reason for this doubtless lies in the fact that soon after their discovery and before their exploitation, the kelp industry underwent a tremendous slump owing to the discovery of iodine in the Chili niter and its extraction therefrom at a much reduced cost, and to the exploitation of the Stassfurt deposits as a source of potash. With the decease of the kelp industry also died the chances of developing by-products from kelp.

Algin and the alginates, and related substances, may upon their exploitation prove of such value in the textile and other industries as to warrant the adoption of the direct lixiviation method of extracting potash and iodine from kelp—the one method which will admit of the full utilization of the organic constituents of the kelp.

#### THE PRESENT USES OF SEAWEED.

*Agricultural.*—The use of seaweed in agriculture as a fertilizer is about as old as that science itself. Of the earliest accounts of the agriculture of England and Scotland, and of the adjacent islands, the consideration of seaweed as a fertilizer constitutes an important part. In these countries the privilege of gathering seaweed on the shores was a subject of barter; and lands carrying this privilege brought a higher price than those without. In certain parts of France and in New England they have found considerable and profitable application.

The choice of the varieties employed is determined, doubtless, largely by chance. The farmer collects the weeds as they are thrown upon the shore in tangled masses and can scarcely pick out one species and leave another. Generally speaking, he is confined to the species which occur in preponderating amount. This is especially true if the weeds are cut from the rocks. These are the *Laminaria* and the *Fuci*. Commingled with them are the eel grasses and other forms of sea growth, animal and vegetable. The *Fuci* (*vesiculosus* and *nodosum*) on the New England coast constitute at least three-fourths of the covering of tidal rocks.<sup>1</sup>

TABLE XXX.—*Composition, by species, of a mass of seaweed thrown up by the tide at Thanet.*

[Leaflet No. 254, Board of Agriculture and Fisheries.]

	Per cent.
<i>Fucus serratus</i> .....	59.7
<i>Glyceria maritima</i> .....	4.3
<i>Salicornia herbacea</i> .....	
<i>Laminaria</i> .....	2.5
<i>Ulva</i> .....	1.4
<i>Fucus vesiculosus</i> .....	.6
Sea mat.....	1.2
Miscellaneous debris.....	30.3

Analyses show that the various seaweeds have different values as fertilizers. The *Laminaria* is richer than the *Fucus*, and those gathered in the early summer are more valuable than those collected in the fall. The *Lestera*, *Salicornia*, and *Glyceria*, it is recognized by the farmer, are distinctly poorer than the *Laminaria* and *Fuci*. They are more fibrous and do not decompose so readily.

<sup>1</sup> Wheeler and Hartwell Bull. 21, Rhode Island Experiment Station.

The composition of the collateral substances occurring commingled and collected with seaweed is set forth in the following table:

TABLE XXXI.—*Composition of other substances commonly found with drift kelp.*

[Pamphlet 254, Board of Agriculture and Fisheries.]

Constituent.	<i>Zostera marina</i> (Jersey).	<i>Salicornia herbacea</i> and <i>Glyceria maritima</i> (Thanet, Kent).	Sea mat (Thanet, Kent).	Smallshells; débris (Thanet, Kent).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Organic.....	76.32	61.50	25.80	21.86
Nitrogen.....	.68	2.15	2.37	.97
Ash.....	23.68	38.50	74.20	78.14
Sand.....	3.62	16.68	25.80	44.85
Pure ash.....	20.06	21.82	48.40	33.29
Phosphoric acid.....	.70	.04	.64	.02
Potash.....	.69	1.28	1.30	.48
Calcium carbonate.....				21.80

The method of application of seaweeds to the soil varies but slightly from place to place. In the majority of cases, they are added direct, either as a top dressing, in summer or autumn, or for plowing under. In rare instances, they are composted, being stacked in piles, with alternate layers of lime, to rot. This has the advantage that the disintegrated weeds are more easily spread uniformly over the land and that a more compact and less watery mass remains to be hauled to the fields. The use of gypsum is recommended as a substitute for that of lime in the composting.

Because of the readiness with which they rot and with which their soluble and valuable constituents are leached out by the rain, the plants are hauled directly to the compost heaps or to the field without curing. This necessity is an unfortunate circumstance, as in the wet condition the plants contain about 80 per cent of water.

On the soil, as a surface dressing or plowed under, the weeds decompose rapidly and their constituents, which play a rôle in the plant growth, are easily rendered available. Thus, while the beneficial effects are short lived, there is the counterbalancing fact that their beneficial effects are immediate.

Harvey is quoted as saying that the *Laminaria* decompose rapidly and "melt" in the ground and that, therefore, in common with other weeds, they should be used fresh, instead of being allowed to lie "in the pit where they soon lose their fertilizing properties." It is the verdict of the Rhode Island farmers that it does not pay, as a rule, to compost seaweeds. This is especially true of the fiberless, more gelatinous varieties, such as Irish moss. It is claimed that the time consumed in the labor of composting is worth more than the improved condition of the weeds.<sup>1</sup> When mixed with stable manure, their decomposition, it is said, assists in that of the manure, and improves the condition of the latter when peat has been used in bedding. They are supposed to promote the fermentation of the peat. Their ready decomposition in the soil insures against their opening up and drying out light soils, as stable manure sometimes does.

<sup>1</sup> Bull. 21, Rhode Island Experiment Station.

In Scotland seaweed appears to be held in special favor on the southwest coast, where the soil is light. It is, perhaps, the chief fertilizer used for early potatoes on the Ayreshire coast, being applied at the rate of 25 to 30 tons per acre in the autumn, and then plowed under.

In the trucking region of south Cornwall the sea plants, as a rule, are not used in the fresh condition, but are mixed with sand and are allowed to rot. The resulting material is applied, together with guano and superphosphate, for early potatoes and cauliflower. On the north Devon coast seaweed is used for potatoes and other root crops. Some is shipped inland by barges for purposes of "spring dressing."

On the Scilly Islands seaweed is applied in amounts as great as 50 tons per acre for early potatoes, and in smaller amounts for wheat. Some is allowed to rot in piles for garden purposes. Here the *Fucus* is preferred to the *Laminaria*. The material is generally gathered between September and March.

In the isle of Thanet seaweed is applied to alfalfa (lucerne) at the rate of 10 to 15 tons per acre in the autumn, and is raked off in the spring. It is also applied to the land, and plowed under before planting in growing garden as well as farm crops.

In Jersey use is made of both drift and cut weed; the fresh weed is applied at the rate of 45 tons per acre about the middle of September to lands which are to be planted in potatoes the following spring. This is dug into the soil in December and January.

Use is also made of seaweed, which has been collected, dried, and stacked, the curing of which constitutes a regular summer occupation for some of the poorer people of the island.<sup>1</sup>

The percentage composition of fresh seaweed as gathered is given in the subjoined table:

TABLE XXXII.—*Composition of fresh seaweed.*

Constituent.	Thanet.	Scotland.	Jersey.	United States (average of many analyses).	Canada, 2 single analyses.	
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	75.00	77.41	77.50	81.50	63.49	79.23
Organic matter.....	14.45	16.30	18.10	.....	27.93	15.23
Nitrogen.....	.48	.54	.27	.73	.47	.17
Potash.....	1.00	1.24	.80	1.50	2.02	.76
Phosphoric acid.....	.02	.09	.12	.18	.11	.04

<sup>1</sup> Leaflet No. 254, Board of Agriculture and Fisheries.



An interesting comparison of the composition of the dry matter of seaweed with that of certain other farm products is given in the following table:

TABLE XXXIII.—*Comparison of seaweed with farm crops.*

[Leaflet No. 254, Board of Agriculture and Fisheries.]

Constituent.	Fucus and Laminaria (mean).	Buck-wheat (at flowering).	Rye (in ear).	Mustard (at flowering).	Meadow hay.	Clover hay.	Marigolds (roots).	Wheat straw.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Nitrogen.....	1.83	1.18	0.70	2.30	1.74	2.60	1.67	0.61
Pure ash.....	25.47	12.00	.....	14.70	7.20	6.85	7.21	5.35
Potash.....	4.40	4.44	2.10	4.20	1.78	2.22	3.77	.80
Phosphoric acid.....	.24	1.22	.59	1.00	.43	.66	.62	.26

The actual value of the fertilizing material present in a ton of seaweed of the average composition by the usual methods of estimation would be \$1.90 to \$2.40. This leaves out of account the sodium, calcium, and magnesium salts which, under proper conditions, are of distinct value.

As seaweeds more or less entirely take the place of stable manure it is only fair in estimating its value to compare it with manure. In such a comparison a distinct advantage is possessed by seaweed, in that it is free from seeds of land plants, so that its application does not introduce seeds of grass and weeds, as does that of manure. The use of manure as a fertilizer for certain tubers, especially potatoes, promotes the development of injurious growths and the inoculation of the soil with the bacteria of plant diseases. Because of its freedom from such disadvantages, seaweed is to be recommended.

Seaweeds have found use as a fertilizer for various crops. On account of their high content of potassium salts they are regarded as a potassium-bearing fertilizer and are especially recommended for use with those crops whose growth is especially promoted by potassium fertilizers. They can scarcely be regarded as a balanced or complete fertilizer on account of their low phosphorus content. Their mixture with some phosphate should be advantageous.

On the Hebrides Islands and other outlying British islands seaweed constitutes the main fertilizer, and, according to Mr. A. V. Campbell, of Rothamsted, it is the dependence of the Jersey potato growers. At Rye Beach, N. H., the great success had there with red clover is attributed to the use of seaweed applications. The practice dates from the settlement of the colony.

The extent of the use of seaweed as a fertilizer is not limited by the amounts available, for they are enormous, but by the distances from shore the plants can be hauled profitably. The comparatively great amount of water contained by the fresh plants makes them exceedingly heavy and bulky and adds greatly to the expense of their cartage. Indeed, this fact makes it unprofitable for the farmer to transport them any great distance. Accordingly, it is found that they are rarely used on land lying more than 10 or 15 miles from the shore.

The seaweed used as fertilizer in Rhode Island during the year 1885, according to the Rhode Island State census, was valued at

\$65,044. For the sake of comparison, it may be cited that the value of the commercial fertilizer used in the State during the same year was \$164,133.<sup>1</sup>

*As a food.*—The utilization of seaweed for dietary purposes has received more attention and has undergone a greater development in Japan than in any other country.

The three main products of seaweed which are used as foods bear the local names of kanten, kombu (or kobu), and amanori (or laver). Kanten, or "seaweed isinglass," is prepared from the *Gelidia* by drying or curing in the sun, during which operation they become bleached, and by boiling out the jelly formed. This is subsequently molded or shaped into the desired forms. The product is pearly white, shiny, and semitransparent, and is tasteless and odorless. In cold water it swells but does not dissolve, but in boiling water it dissolves, and on cooling it forms a jelly.

In Japan kanten is used for food in the form of jellies and as adjuncts to soups, sauces, etc., and in foreign countries in the various food preparations where gelatine is required. It finds application in the textile industries, as a coagulant for clarifying the various liquids for drinking purposes, and in China as a substitute for edible birds' nests. Kanten is the agar-agar employed by the bacteriologist as a culture medium.

TABLE XXXIV.—*Analysis of kanten.*

[Analyses by (1) Kellner, Agricultural College, Tokyo University, and (2) Imperial Fisheries Bureau.]

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Water.....	22.80	22.39
Protein.....	11.71	6.85
Fiber.....		6.73
Carbohydrates.....	62.05	60.32
Ash.....	3.44	3.81

The production for 1900 was 2,370,517 pounds, valued at \$576,500; for 1901, 2,177,867 pounds, valued at \$534,232; for 1902 (estimated), 3,000,000 pounds, valued at \$750,000. The exports of kanten for 34 years ending in 1902 were 49,595,288 pounds, valued at \$7,323,455. In 1902 the largest exportation was reached, equaling 2,207,455 pounds, valued at \$544,272.

Kombu is a general term applied to various sorts of foods made from kelps of the genera *Laminaria* and *Alaria*. The plants are cured on shore and are then tied into bundles for shipment to the kombu manufactories. There they are put through an involved process during which they are sorted, dyed, cooked, and pressed, and cut into desired shapes.

Kombu, in its various shapes, is one of the staple articles of diet of the Japanese. Some varieties are eaten directly, while others are cooked with the various meats and vegetables. Its composition varies somewhat, being determined by the species of kelp from which it is made. The subjoined table of analyses, by Oshima, Agricultural College, Sapporo, gives the chemical composition of the principal species of kelp used in this industry.

<sup>1</sup> Bull. 21, Rhode Island Experiment Station.

TABLE XXXV.—Composition of principal species of kelp used in the kombu industry.

Species.	Water.	Protein.	Fat.	Soluble nonnitrogenous matter.	Fiber.	Ash.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
<i>Laminaria angustata</i> .....	22.82	5.49	1.52	47.83	4.55	18.69
<i>Laminaria longissima</i> .....	25.94	6.72	1.73	31.90	6.42	27.20
<i>Laminaria japonica</i> .....	22.97	4.96	1.59	47.49	5.83	17.16
<i>Laminaria ochotensis</i> .....	23.99	6.66	.86	41.92	6.03	21.31
<i>Laminaria religiosa</i> .....	22.75	4.72	.82	42.85	10.20	18.63
<i>Laminaria fragilis</i> .....	23.10	4.03	.65	40.39	7.15	24.66
<i>Anthrothamnus bifidus</i> .....	24.44	5.82	.74	45.57	6.44	17.00

The amounts of kelp gathered for the kombu manufactories and the sums paid the fishermen therefor during three years, as recorded by official census, are:

Year.	Pounds.	Value.
1899.....	58,929,963	\$417,332
1900.....	53,750,650	301,380
1901.....	76,806,975	464,082

Figures for the value of the finished product are not given; but that is estimated as an increase of 60 to 75 per cent over the cost of the raw material.

The exports for the five years, 1898–1902, inclusive, are given as:

Year.	Pounds.	Value.
1898.....	53,031,761	\$355,646
1899.....	61,596,594	473,041
1900.....	48,054,681	441,864
1901.....	81,212,970	774,164
1902.....	52,491,166	404,744

*Amanori or laver.*—Amanori or laver is a preparation made from the seaweed of the genus *Porphyra*. These plants are obtained almost exclusively from groves artificially propagated. The algae culture of the red laver (*Porphyra lanceolata* or *vulgaris*) is one of the most important branches of the seaweed industry. In 1901, 2,242 acres were under cultivation and produced a crop of 4,769,000 pounds, valued at \$239,536. In the Tokyo region, where 951.5 acres were under cultivation, the product per acre was valued at \$156.

The preparation of laver is simple as compared with that of kombu. The plants are gathered, cleaned, cured, and tied up into bundles for the market. It is eaten in soups, with sauces, and in other ways. The composition of *Porphyra* is given in the following table:

TABLE XXXVI.—Results of analyses of *Porphyra*.

Locality.	Weight 10 sheets.	Water.	Protein.	Fat.	Ash.
	<i>Grams.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Suna.....	41	14.58	32.44	0.70	9.09
Do.....	37	16.40	35.63	.50	9.34
Fukagawa.....	32	20.42	36.26	1.21	8.58
Shinagawa.....	30	15.48	34.36	.65	10.09

The foods produced in Japan in the form of kanten, kombu, and laver have an annual value of \$1,778,000. The value of the exports of kanten and kombu alone is \$948,000.

Small amounts of the seaweed foods are exported to this country, but so far they have not gained very great popularity. As an article of export, however, kanten and kombu might be manufactured in this country, as the plants from which they are prepared are found in abundance on our coasts.

Concerning the Japanese seaweeds, Kinch<sup>1</sup> says:

There is some confusion in the books about the names and species of the two principal seaweeds. Thunberg and Kaempfer give to kombu the name *Fucus saccharinus*, *Fucus* being at that time the generic appellation of nearly all algae. Thunberg mentions that it is sometimes called "komb" or "kobu" or even "kosl." In Golownin's narrative of his captivity in Japan (1811-1813) he mentions the gathering of seaweed of a kind called by the Russians "sea cabbage" and by the Japanese "kambon." This is now called in Yezo "kombu," which name is on this island generally pronounced "kobu." The English translator of Golownin refers this seaweed to the kind known as dhulish or dulce in the north of Scotland and Ireland, and when boiled as sloke, sloak, or slaak, but this latter is *Porphyra lanceolata*, nearly allied to the Japanese nori. In some books *Fucus saccharinus* and *Laminaria saccharina* are spoken of as different substances, but the former is merely the old name. An allied species, *L. potatorum*, is used by the natives of Australia and in New Zealand and Van Diemens as food and for making instruments, and still another species is used on the west coast of South America.

Closely allied to *Rhodymenia palmata* is a Japanese alga, *R. textorii* (Suringar). *Plocaria candida* is the agar agar of the Malays and imported to England as Ceylon moss, and from this species the edible birds' nests so esteemed in China are principally constructed. *Gelidium corneum* (Lamour.) is often sold as agar agar. It is the *algue de java*, known in China as Niu-mau, or ox-hair vegetable. Its gelatinizing principle has been called gelose. *Gracilaria lichenoides* is also known as agar agar.

In Europe the *Laminaria*, *Sacchorera*, and *L. digitata*, the former said to contain as high as 15 per cent of a sugar resembling mannite, are eaten.

The so-called Irish moss, or carageen, *Chondrus crispus* (Lingbye), is perhaps the most extensively used for dietetic purposes of the seaweeds in Europe at the present time; a closely allied species, *Chondrus punctatus* (Suringar), occurs in the Japan Sea.

The dulce of the Scotch and the dylisk, dillish, dullisgor, dulleisg (leaf of the water) of the Highlands is *Rhodymenia palmata* (Grev), which also contains mannite and is sudorific. It is largely used in some of the maritime countries of Europe from Iceland to Greece. In Kamschatka a spirituous liquor is made from it. Cattle are very fond of it. Before tobacco was so easily obtained the Highlanders and Irish were in the habit of chewing it. It is parasitical on *Fuci* and *Laminaræ*. The dulce of the southwest of England is another species, *Iridaea edulis* (Bory).

The Irish moss has found some use as a food in New England, where it is used as a jelly in certain dietary preparations, resembling blancmange. To extract the jelly, the weed is placed in a cloth bag and boiled in water. The extract is flavored and otherwise prepared for eating. On the New England coast the Irish moss is gathered from the rocks, where it grows, by means of specially constructed rakes. It is then cleansed and carefully cured by spreading on the beach in the sun. It is sent to the market in barrels holding 100 pounds. The wholesale price in 1903 was 5 to 5.5 cents per pound. The census of the Bureau of Fisheries for 1902 showed that 136 men were occupied in the Irish moss industry and employed apparatus—boots, rakes, etc.—valued at \$12,000. The output that year was 740,000 pounds, with a market value of \$33,000.

<sup>1</sup> Trans. Asiatic Soc. Japan, 8 (III), 369 (1880).

It is of interest that the price of Irish moss in this country, in 1835, was \$1 per pound, and that this price declined to 25 cents in 1853 and to 3 to 3.5 cents per pound in 1880. Its present retail price, in boxes of 1 pound and one-half pound, is 45 and 25 cents, respectively.

The Irish moss industry in this country is confined practically to Massachusetts and New Hampshire.

As a cattle food, it is stated, the Irish moss has also found some application, especially for feeding young calves and pigs. In both Norway and Scotland the herds visit the shores at low tide to feed on the common Fuci. These are gathered by the Norwegian and Scottish peasants, are boiled and mixed with meal, and the resulting mixture is fed to pigs, horses, and cattle.

The following table contains results of analysis of two varieties of sea plants occurring on the American coast:

TABLE XXXVII.—Results of analyses of American sea plants.

[Cited from Bulletin 21, Rhode Island Experiment Station.]

Constituent.	Eel grass ( <i>Zostera marina</i> ).	Rock weed ( <i>Fucus vesiculosus</i> )
	Per cent.	Per cent.
Water.....	26.64	27.11
Fat.....	.19	.67
Cellulose.....	9.05	4.40
Nitrogen-free extract.....	32.02	41.14
Protein.....	6.03	8.21
Ash.....	26.07	18.47

We are not aware that seaweeds have been tried to any extent as a cattle feed in this country, though it is not improbable the Irish moss and even other varieties might be found useful, more especially in the rearing of calves and swine. The question of this economical application as a cattle food, however, would depend largely upon the cost and supply of other foods. It would doubtless be a question if cattle accustomed to the best class of foods would take so readily to a partial diet of seaweed as do the Scotch and Norwegian herds.<sup>1</sup>

*Seaweed glue*.—In Japan seaweed glue is known as “funori.” It is prepared by a simple operation from the seaweed of the genus *Gloiopeltis* (*G. coliformis* and *G. intricata*).

Funori, *Gloiopeltis intricata* (Suringar), is largely used for making size, which has numerous applications, and Tsunomata, *Gymnogongrus pinnulatus* (Harvey) or *G. japonicus* (Sur.), is used for the same purpose.<sup>2</sup>

This gum is prepared from the plants directly. They are gathered, cleansed, and cured in such a way that during the operation they become coalesced into sheets. The sheets are done up into bundles of convenient size for the market.

Funori is used principally for glazing and stiffening fabrics and as a substitute for starch. Its price varies with its quality, from 24 to 3 cents per pound. The output and its value for the five years preceding and including 1901 is given as follows:

<sup>1</sup> Wheeler and Hartwell, loc. cit.

<sup>2</sup> Kinch, loc. cit.

TABLE XXXVIII.—Output and value of kelp.

[Bulletin 21, Bureau of Fisheries, 1904.]

Year.	Quantity.	Value.
	<i>Pounds.</i>	
1897.....	1,429,111	\$53,857
1898.....	987,862	41,478
1899.....	2,799,253	145,326
1900.....	2,135,677	77,083
1901.....	2,943,383	130,809

Numerous gums possessing, it is claimed, valuable qualities have been prepared from the kelps of the British Islands, and a discussion of these and their proposed uses was given under the consideration of the by-products of the lixiviation method of extracting potash from kelp, and will not be repeated here.

*Iodine.*—The extraction of iodine from kelp is among the newer of the kelp industries of Japan. Its development has reached such a point that the iodine produced is sufficient to meet the domestic needs. Hence, no iodine is imported. That the industry there probably has reached its greatest possible development is indicated by the fact that the manufacturers are already experiencing considerable difficulty in obtaining sufficient raw material wherewith to operate. This situation may be relieved, however, by the adoption of algae-cultural methods for the propagation of kelp groves. The seaweeds are burned in the crude, heap-burning method described in another paragraph, and the ashes are leached by the burners or are shipped to the lixiviators.

Glasgow has been the center of the iodine-from-kelp industry since the inception of that industry, about the year 1841. The imports of kelp (kelp ash) into the Clyde in that year amounted to 2,565 tons. In 1845 there were four small works engaged in the extraction of iodine and utilizing 6,000 tons of kelp; this number was increased to 20 in 1846. In 1877 this number had decreased to three. The price of iodine was the object of speculation and varied at times with great suddenness. The range in price during the days of the industry was between \$1 and \$8 per pound, the price of the raw material remaining the same the while. The following table gives the history of the Glasgow kelp industry during 35 years of its existence.

TABLE XXXIX.—Amount of kelp ash lixiviated and the price paid at Glasgow, 1841-1875.

[Stanford, Chemical News, 35; 172 (1877).]

Years.	Kelp used.	Price of iodine per pound.	Average.	
			Quantity.	Price.
	<i>Tons.</i>		<i>Tons.</i>	
1841-1845.....	1,887-6,086	\$1.12-\$7.46	3,133	\$2.82
1846-1855.....	3,627-11,421	2.08-5.10	5,811	3.10
1856-1865.....	6,349-14,018	1.20-3.28	9,730	2.12
1866-1875.....	8,116-10,923	2.40-8.16	9,187	3.83

At the beginning of the nineteenth century kelp (kelp ash) was worth \$100 to \$110 per ton, and the western islands of Scotland alone produced 20,000 tons (value \$2,000,000). The importation of barilla reduced the price to an average of \$52 per ton. Later the duty was taken off barilla and salt, with the result that by 1831 the price of kelp had fallen to \$10 per ton. In 1845 the development of the iodine industry enhanced the value of kelp, but only of those varieties rich in iodine. These were also rich in potassium chloride, so a use for this salt was developed. At one time the potassium chloride had a value of \$125 per ton. The development of the Stassfurt deposits and the exploitation of the potassium salts there obtained caused a depression in that price to about one-third.

Iodine is present in the niter of the Chile deposits to the extent, it is said, of 0.16 per cent, or 3.58 pounds per ton. Outside of Japan, nearly all the iodine now produced comes from the Chile deposits.

To-day the only producers of iodine from kelp in Scotland are the British Chemical Co. and H. C. Fairlie & Co. (Ltd.), Falkirk, and it is said that the business is much depressed and is yearly declining in volume.

J. W. TURRENTINE.

## APPENDIX R.

### A DISCUSSION OF THE PROBABLE FOOD VALUE OF MARINE ALGAE.

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Articles of diet may, broadly speaking, be divided into two general classes—stimulants, or appetizers, and foods proper. Some members of the first class, like the condiments, have no food value whatever. By food value is meant capability to act as a source of material for growth and repair, or of energy. The condiments must not for that reason be neglected. They are probably necessary under certain conditions, particularly in the Tropics, to counteract by artificial stimulation of the appetite the effect which the high temperatures have of cutting down the heat production in the body by limiting the food consumed. Without the stimulation afforded by condiments, not sufficient food might be taken to fulfill the minimal requirements of the body. However, not all members of the first class are without food value. Many articles of diet have a certain food value, though, in the main, they serve either to stimulate the appetite or to give bulk to the food. This is true of some of the vegetables like lettuce and cabbage which consist mostly of water, cellulose, and salts. Since cellulose does not seem to be well utilized by man, though it is better utilized by herbivorous animals, the food value of these articles, particularly since their price is high, is probably not great.

The foods proper perform in the main two functions. They supply the material from which the tissue waste is repaired, as well as the energy with which the work and functions of the organism are carried on. The main materials in the foods which perform these functions are the salts, the proteins or albuminous substances, the fats, and the carbohydrates or sugars. The salts furnish no energy and are usually present in such abundance in most diets that it is not necessary as a rule to consider them in estimating the value of a food. The proteins, or albuminous substances, are perhaps the most important, since they are quite indispensable and furnish both material to repair tissue waste as well as energy. The fats and also the sugars are in the main energy-yielding foods, furnishing the fuel for the organism, the fats having a higher energy value than the sugars, though less digestible.

Hence it is quite evident that to estimate the value of any article of diet it is necessary to know its chemical composition. It is indispensable to know just how much carbohydrate, protein, and fat it contains. However, it is not sufficient to know what the proportions of these substances are; it is necessary, also, to know their nature. Thus not all proteins are of equal food value. Gelatin, for instance, is not capable of supporting life alone, while some other proteins may. The same thing may be said of the fats, for fats with



a high melting point are less well absorbed than those with a low one. The carbohydrate starch is an excellent food; cellulose an indifferent one. A consideration of the probable food value of marine algae must, therefore, be preceded by a study of their chemical composition. The substances which are of interest in this connection are the proteins, fats, and carbohydrates.

#### PROTEINS OF SEAWEEDS.

Unfortunately, these can be dismissed in a few words, because almost nothing is known about them. Little has been done with them in recent years. The only data that exist are on the "crude protein" of a few forms. The following table gives the figures for the air dry material:<sup>1</sup>

	Water.	"Crude protein."
	Per cent.	Per cent.
<i>Ulva latissima</i> .....	29.75	13.35
<i>Valoniopsis sagittifolia</i> .....	7.62	5.36
<i>Gracilaria conferva</i> .....	20.01	16.25
<i>Fucus vesiculosus</i> .....	27.11	8.21
<i>Vaucheria pilus</i> .....	20.50	6.88

Warington gives the following figures<sup>2</sup> for the dry substance:

	Per cent.
<i>Porphyra vulgaris</i> .....	6.32-26.14
<i>Enteromorpha compressa</i> .....	12.41
<i>Capea elongata</i> (Laminaria).....	8.99
<i>Cystoseira</i> sp.....	8.24
<i>Laminaria saccharina</i> .....	7.79

The introgenous material is much greater in young than in old plants (Warington).

Of the nature of the protein nothing whatever is known, except that it is supposed that the iodine present is organically combined with protein.<sup>3</sup> The evidence for this is not conclusive. It is reasoning by analogy from the conditions which are known to obtain among the corals. Certainly in *Bonnemaisonia asparagoides*, a member of the order of Florideae, the iodine seems to be free, for starch is blued directly.<sup>4</sup> From the fact that many marine algae contain very large quantities of sulphur one may venture the guess that these may contain protein very rich in sulphur. From the fact that *Iridea edulis* yields an ash with 14 per cent phosphoric acid ( $P_2O_5$ ) one may guess that it may contain protein very rich in phosphorus. This, as far as could be ascertained, constitutes nearly all that is known about the nitrogenous material of marine algae. If the above figures are reliable the nitrogen content of many of the marine algae would seem to be as high as that of many forage plants and vegetables. However, without further investigation it can not be said that they have, as regards the protein, the same food value. The ordinary method

<sup>1</sup> Wolff: Aschenanalysen, 2, 108 (1880).

<sup>2</sup> Warington, R.: Agricultural Chemistry in Japan. The Chemical News, 40, 195 (1879).

<sup>3</sup> Eschle: Ueber den Jodgehalt einiger Algenarten Zeitschrift für physiologische Chemie, 23, 30 (1897).

<sup>4</sup> Golenkin, M.: Algologische Notizen. Bulletin de la Société Impériale des Naturalistes de Moscou. N. S., 8, 257 (1894).

of estimating "crude protein" is to determine the nitrogen and multiply by the factor 6.25. This is done on the assumption that all the nitrogen is present in the form of protein and that the protein has the composition of average protein. Without further investigation it is impossible to say whether either of these assumptions is warranted. We know that in many plants a considerable part of the nitrogen is present in the form of organic bases, amides, or even nitrates. The organic bases, such as betain and cholin, have no food value, while the amides are useless to man, though it is possible they are utilized by herbivora. Moreover, as already stated, all proteins are not of equal value. It is a matter of common knowledge that the proteins in such substances as gristle are not as well utilized as more soluble ones. As long as we know nothing concerning the quantity of nonprotein nitrogen in algæ, nor of the quantity and nature of the proteins present in them, it is idle to speculate concerning their value as a protein food. Investigations of these problems, which are very greatly to be desired, may prove that some of the algæ have the protein food value of vegetables and fodders. It is not likely that any of them, as far as the protein is concerned, will prove to have anything like the food value of our most important foods—like the cereals and meats. It may, perhaps, be worth while to add that the desirable investigations which have just been sketched should be supplemented by actual feeding experiments upon man and animals.

#### FATS.

The only fact concerning the fat content of marine algæ that a careful search of the literature has revealed is that *Fucus vesiculosus* in the air-dry state contained 27.11 per cent water and 0.67 per cent fat, while *Ulva latissima*, *Valonia aegagrophila*, *Sphaerococcus confervoides*, *Enteromorpha intestinalis*, *Zoostera mediterranea*, contain less. *Solenia attenuata* contains 3.87 per cent and *Vaucheria pilus* 2.94 per cent of fat.<sup>1</sup> It seems that no other species have been examined. There do not even seem to be data on the ether-soluble material. From these few analyses it would seem that, as was to be expected, the fat content is not great. Probably all species contain some of it, since fat is never quite absent from living things. Nothing is known of the nature of the fat. The chances, therefore, are that the fat of marine algæ is not likely to be an important factor in giving them food value. If any of the plants contained greater quantities they would in all probability have attracted attention.

#### CARBOHYDRATES OR SUGARS.

Aside from water, salts, and protein, the main constituents of marine algæ seem to be carbohydrates. In consequence, these have been most studied. Nevertheless, our knowledge is full of gaps, either because the investigations are antiquated or because only a few European or Japanese species have been examined. Not many characteristically American ones have been studied at all, and these are mostly rock weeds, not kelps.

<sup>1</sup> Sestini, F., Bomboletti, A., Benzoni, V., and Del Torre, G.: Sopra alcune piante marine della Laguna Veneta. *Le Stazioni Sperimentali Agrarie Italiane* 5, 207 (1877). See also *Centralblatt für Agrikulturchemie* 7, 875 (1878).

Before discussing the distribution of carbohydrates among these plants it is necessary to consider the various kinds of carbohydrates which occur in them. Carbohydrates are all derivatives of simple sugars, the commonest of which are glucose and fructose. Such simple sugars contain, usually, six carbon atoms. Sugars with a smaller number of carbon atoms also occur, but only those with five and six are of interest in this connection. Those with six carbon atoms are termed hexoses; those with only five, pentoses. By the combination of two molecules of simple sugars more complex sugars, called bioses, are formed. The commonest bioses are cane sugar and milk sugar. More than two molecules of simple sugars may combine to form more and more complex compounds. Thus starch is a combination of a large but as yet undetermined number of molecules of the simple sugar glucose. Such complex carbohydrates composed of a large number of simple sugar molecules are termed polysaccharides.

The carbohydrates of interest in this connection may therefore be classed as follows:

Simple carbohydrates:

Glucose or dextrose.  
Fructose or levulose.  
Mannose.  
Galactose.  
Pentoses and their derivatives,  
the methylpentoses.

Bioses.

Polysaccharides:

Dextrans consisting of glucose.  
Starch.  
Cellulose.  
Galactans consisting of galactose.  
Mannans consisting of mannose.  
Pentosans consisting of pentose.  
Levulans consisting of levulose.

Besides the sugars and carbohydrates, the closely related alcohol mannite is said to occur in *Laminaria*,<sup>1</sup> *Halydria*, and *Fucus vesiculosus*.

Free simple sugars like glucose do not seem to occur as such to any appreciable extent in the marine algae, though reported by Bauer in *Laminaria*. Bioses, such as cane sugar, also seem to be rare or absent. Most abundant, on the contrary, are the polysaccharides.

Of polysaccharides starch does not seem to occur very abundantly. It is said to occur in *Neomeris kelleri* and *Polyphysa peniculus* and in various species of the order Florideae. However, most of the statements concerning the occurrence of starch are unreliable and need verification, since in many instances they are based on the microchemical test with iodine. This test, as is well known, is positive with a number of other polysaccharides.

Other dextrans, more or less resembling cellulose and not as yet sufficiently investigated chemically, seem somewhat more abundant. Cellulose has been reported in *Vaucheria*. A dextran has been reported by Bauer<sup>2</sup> in *Laminaria* and also by Van Wisselingh. Sestini<sup>3</sup> gives the following table of the cellulose and water content of air-dry algae:

<sup>1</sup> Stenhouse, J., Ueber das Vorkommen von Mannit in *Laminaria* und einigen anderen Seegräsern. *Liebig's Annalen*, 51, 349 (1844).

<sup>2</sup> Bauer, R. W., Ueber eine aus *Laminariaschleim* entstehende Zuckerart. *Berichte der Deutschen Chemischen Gesellschaft*, 22, 618 (1880).

<sup>3</sup> Sestini, F., et al., op. cit.; Sestini, F., *Sopra alcune piante marine utili all'agricoltura*. *Ibid.*, 5, 102 (1876).

## Cellulose and water content of air-dry algae.

Algae.	Water.	"Cellulose."
	Per cent.	Per cent.
<i>Ulva latissima</i> .....	29.75	1.77
<i>Valonia egagrophilla</i> .....	7.62	3.65
<i>Gracilaria confervoides</i> .....	20.01	3.10
<i>Fucus vesiculosus</i> .....	27.11	4.40
<i>Vaucheria pilus</i> .....	20.50	5.89

Unfortunately these determinations were made by an antiquated method, and it is doubtful whether the substances termed "cellulose" were actually such.

Galactans seem of all polysaccharides the most widely distributed. They occur in *Gracilaria lichenoides*;<sup>1</sup> in *Gracilaria coronopifolia*,<sup>2</sup> *Asparagopsis sanfordiana*,<sup>2</sup> *Gymnogongrus vermicularis americana*,<sup>2</sup> *Hypnea nidifica*,<sup>2</sup> *Ahnfeldtia concinna*,<sup>2</sup> *Gymnogongrus disciplinalis*,<sup>2</sup> *Porphyria laciniata*,<sup>3</sup> and probably in *Fucus amylaceus*.<sup>1</sup> They are also found in Chinese moss (*Sphaerococcus lichenoides*)<sup>4</sup>, in agar agar (*Gelidium corneum*),<sup>4</sup> and in Irish moss (*Chondrus crispus*).<sup>5</sup> Galactan has also been reported in *Sphaerococcus crispus* (Wisselingh) and *Gigartina mamillata*.<sup>6</sup> It is therefore evident that galactans are very widely distributed. Perhaps they occur in all red algae.

Mannan has but rarely been reported. Tollens and Oshima<sup>7</sup> found it in *Porphyria laciniata* together with galactan and pentosan. It also occurs in *Haliseris pardalis*,<sup>8</sup> a Hawaiian edible form. These seem to be the only well-authenticated cases, but mannite, which in plants generally seems to be derived from mannan and vice versa, has been reported by Stenhouse<sup>9</sup> in *Laminaria*, *Halydris*, and *Fucus vesiculosus*. It is therefore likely that these plants contain mannans.

Pentosans, on the other hand, are most abundant. They occur in Japanese "Nori" (*Porphyria laciniata*, *Laminaria*, and other seaweeds).<sup>10</sup> Methylpentosans occur in *Fucus*,<sup>11</sup> in *Laminaria*,<sup>12</sup> *Ascomyllum nodosum*,<sup>13</sup> *Asparagopsis sanfordiana*,<sup>14</sup> *Enteromorpha*

<sup>1</sup> Greenish, H., Untersuchung von *Fucus amylaceus*. Berichte der Deutschen Chemischen Gesellschaft, 14, 2253 (1881); Morin, H., Sur la gelose. Comptes Rendus Académie des Sciences, 96, 924 (1883); Bauer, R. W., Ueber den aus Agar-Agar entstehenden Zucker, über eine neue Säure aus der Arabinose nebst dem Versuch einer classification der gallertbildenden Kohlehydrate nach den aus ihnen entstehenden Zuckerarten. Journal für Praktische Chemie, N. S., 36, 367 (1884).

<sup>2</sup> Swartz, M. D., Nutrition. Investigations on the Carbohydrates of Lichens, Algae, and Related Substances. Trans. Connecticut Acad. Arts and Sciences, 16, 247-382 (1911).

<sup>3</sup> Oshima, Kintaro, and Tollens, B., Ueber das Nori aus Japan. Berichte der Deutschen Chemischen Gesellschaft, 34, 1422 (1901).

<sup>4</sup> Payen, M., Sur le gelose et les nids de salangane. Comptes Rendus Académie des Sciences, 49, 521 (1859).

<sup>5</sup> Müther, Untersuchungen über *Fucus* arten, *Laminaria* und *Carrageen*-moos, sowie die hydrolytisch daraus entstehenden Substanzen und über Derivate derselben, besonders *Fucose* und *Fuconsäure*. In. Diss. Göttingen, 1903.

<sup>6</sup> Haedicke, J., Bauer, R. W., and Tollens, B., Ueber Galactose aus *Carrageen*-moos. Liebig's Annalen der Chemie, 238, 302 (1887).

<sup>7</sup> Tollens, B., and Oshima, K., Op. cit.

<sup>8</sup> Swartz, Op. cit., pp. 225, 307, and 313 (1911).

<sup>9</sup> Stenhouse, J., Op. cit.

<sup>10</sup> Oshima, K., and Tollens, B., Op. cit.

<sup>11</sup> Günther, A., and Tollens, B., Ueber die *Fucose*, einen der *Rhamnose* isomeren Zucker aus Seetang. (*Fucus*-Arten.) Ibid., 23, 2585 (1890).

<sup>12</sup> Müther, A., and Tollens, B., Ueber die Produkte der Hydrolyse von Seetang (*Fucus*), *Laminaria* und *Carrageen*-moos, ibid., 37, 298 (1904); Ueber die *Fucose* und die *Fuconsäure* und die Vergleichung der Eigenschaften derselben mit den von Votocek für *Rhodoese* und *Rhodoensäure* angegebenen, ibid., 37, 306 (1904).

<sup>13</sup> Sollied, P. B., Über das Vorkommen von Methylpentosan in Naturprodukten. Chemiker Zeitung, 26, 1138 (1901).

<sup>14</sup> Swartz, Op. cit.

*intestinalis*,<sup>1</sup> *Gracilaria coronopifolia*,<sup>1</sup> *Gymnogongrus vermicularis americana*,<sup>1</sup> *Haliseris pardalis*,<sup>1</sup> *Hypnea nidifica*,<sup>1</sup> *Rhodymenia palmata*,<sup>1</sup> used in Ireland as dulse, and in *Ahnfeldtia concinna*,<sup>1</sup> and *Ulva lactuca*.<sup>1</sup>

Levulans are of very rare occurrence in seaweeds. Sebor reports small amounts in Carragheen moss (*Chondrus crispus*); Cramer in *Acetabularia crenulata* and *mediterranea*.

The occurrence and distribution of the carbohydrates has now been enumerated. Simple sugars are of rare and scanty occurrence. Starch is rare and as yet inadequately studied. Cellulose is not infrequent. Mannan and levulan are rare. Galactan is very common and abundant. Pentosan is perhaps the most abundant of all.

The next point to be considered is the food value of the different carbohydrates. The simple sugars with six carbon atoms are most of them of great food value; but as they do not occur free to any great extent in seaweeds, they can not be of any great importance.

The polysaccharides, on the other hand, are of very varying value. No polysaccharide can be absorbed from the intestines without having first been decomposed into simpler compounds. The value of the polysaccharides will therefore depend upon the ease with which they are decomposed and upon the value of the resulting decomposition products.

This decomposition may be brought about in one of two ways. The enzymes secreted by the intestinal tract may convert the polysaccharides into simple sugars, which are readily absorbed and utilized; or the intestinal bacteria may decompose them into such compounds as simple fatty acids, marsh gas, and the like.

The action of enzymes is limited almost entirely to starch. This is converted into glucose, rendering starch a most excellent food. Unfortunately the quantities of starch discovered in seaweeds at the present date of writing do not seem to be great, so that from this point of view seaweeds do not promise to be of great food value.

No enzyme known to decompose cellulose, galactan, mannan, pentosan, or levulan has ever been found in man or domesticated animals. The decomposition, as far as it takes place at all, must be brought about by intestinal microorganisms.

Now, the ease with which the different polysaccharides are attacked by microorganisms varies greatly. Cellulose seems to be most easily attacked, next mannan, pentosan is very resistant, while galactan is almost unchanged. Hence galactans, in the form of agar-agar, are extensively used by bacteriologists.<sup>2</sup> However, the experiments on which these conclusions are based are merely test-tube experiments. It is probable, as will appear, that some of the polysaccharides are more easily attacked in the intestinal canal. Moreover, the test-tube experiments were carried out with ordinary fermenting and putrifying microorganisms. It is probable that had marine microorganisms been used different results would have been obtained. There must be such organisms in the sea, otherwise there would be accumulations of dead marine vegetation analogous to peat formation on land. This is a question that, for practical reasons, deserves investigation, since it might be possible to make practical use of these organisms in a process of fermentation such as is employed in making ensilage.

<sup>1</sup> Swartz, Op. cit.

<sup>2</sup> Swartz: Op. cit., pp. 323-331.

As already indicated the various polysaccharides, while not very easily attacked in the test tube, behave somewhat differently in the intestines. Cellulose disappears to a considerable extent in the intestinal canal of man, and to a far greater extent in that of the herbivora. It is not absorbed as sugar, but probably for the greater part as butyric and related acids. How far these constitute a food for man is as yet entirely an open question. The best that can be expected of them is that they serve as sources of energy. For herbivorous animals it has been definitely settled that they serve as sources of energy. They are, even for herbivora, not nearly as valuable as starch, sugar, protein, or fat.

Of the pentosans about the same statements may be made. They also disappear from the intestinal canal to a greater or less extent; but usually more extensively in herbivora than in man.

Just how much energy value they have for man is not known, though they are of considerable use to cattle. Together with cellulose they are the main constituents of hay, straw, and roughage generally. The pentosans of a few seaweeds have been fed and it has been shown that in man 100 per cent of dulse pentosan (*Rhodymenia palmata*) disappears in the intestines, while of Lima elecle (*Enteromorpha intestinalis*), a Hawaiian edible seaweed, 69 per cent, and of Limu pahapaha (*Ulva lactuca laciniata* and *Ulva fasciata*) but 34 per cent disappear.<sup>1</sup> It is not known how useful to the organism the material that disappears may be. This could only be determined by experiments in the respiration calorimeter. These have not, hitherto, been undertaken, although it is extremely important that this be done.

The galactans disappear far less easily from the intestines. Less than 11 per cent of the galactan of Irish moss (*Chondrus crispus*) disappears from the intestines of man, of Limu Mananea (*Gracilaria coronopifolia*) 30 per cent, of Limu Huna (*Hypnea nidifica*) 10 per cent, of Limu Akiaki (*Ahnfeldtia concinna*) 60 per cent. How the organism utilizes what disappears is not known.<sup>1</sup>

Concerning the digestibility of a mannan from a seaweed nothing whatever is known. No work whatever on the digestibility of seaweeds for cattle has been done. It is likely to be rather better than for man or dog.

It is evident that no prediction can be made as to the digestibility of any given seaweed unless its chemical composition be known and feeding experiments be performed. As has been shown, even seaweeds that seem to contain similar carbohydrates may behave very differently when fed.

Unfortunately none of the experiments have been performed with any of the kelps of southern California. There is not even any information on the carbohydrates except in the case of *Fucus*, *Laminaria*, and *Gigartina*. The first is said to contain cellulose and pentosan; the second, glucose, starch, pentosan, and mannan; the third, galactan. It is greatly to be desired that they be studied both chemically and physiologically, for some of them may well contain much starch or other valuable material.

In general it may be said there is no proof at present that any but a very few of the seaweeds have more than a moderate food

<sup>1</sup> Swartz, Op. cit.

value. This is rather astonishing, since in Ireland, Hawaii, and Japan<sup>1</sup> enormous quantities of seaweed are consumed. However, they have, no doubt, considerable value as stimulants of the appetite, like lettuce and cabbage. They also serve to give bulk to the food, much as roughage does for cattle. This may not always be an advantage, particularly in the case of seaweeds containing much galactan. Such foods will produce the passage of very bulky stools, which prevent other elements of the diet from being perfectly utilized, just as whole-wheat bread is less perfectly utilized than that made from flour free from bran. The property of some seaweeds, especially agar agar, of making the stools bulky is of advantage in medicine to combat constipation.

These conclusions must be regarded as tentative. Much more work is necessary. It is altogether possible that some seaweeds contain starch or other easily digested dextrins, mannans, or levulans. These might well be valuable foods. At present none are known. Of the seaweeds hitherto investigated some are of moderate food value, like roughage, others, containing galactan, are of little if any value. Some are nothing more than useless ballast.

All this applies to the carbohydrates. Of the utility of the proteins nothing is known. It is much to be desired that experiments on the food value of the proteins be performed, for some seaweeds contain no inconsiderable quantities. It must, however, be borne in mind that the protein is frequently inclosed in a mass of indigestible carbohydrate, which may interfere with the digestibility of the protein.

While most of the seaweeds as such are not very concentrated foods, so far as known at present, it might, perhaps, be possible to make them more digestible by causing them to ferment. The possibility of treating them as ensilage has been indicated. It might even be possible to decompose them by chemical means. Now that the manufacture of alcohol from wood has proved a success, an analogous process might be applied to kelps. Indeed, there exists a French patent for the manufacture of alcohol from seaweeds,<sup>2</sup> though experts have expressed doubts as to its commercial possibilities.<sup>3</sup>

C. L. ALSBERG.

<sup>1</sup> Swartz, *Op. cit.*

<sup>2</sup> H. Simon & J. Jean. Fr. Pat. Nr. 412955.

<sup>3</sup> *Cf. Zts. f. Spiritus Ind.* Vol. 88, p. 589; *La Sucrerie ind et colon.* 1910, No. 14, p. 328.

## APPENDIX S.

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## APPENDIX T.

### A REFERENCE LIST TO THE LITERATURE OF THE MARINE ALGÆ.

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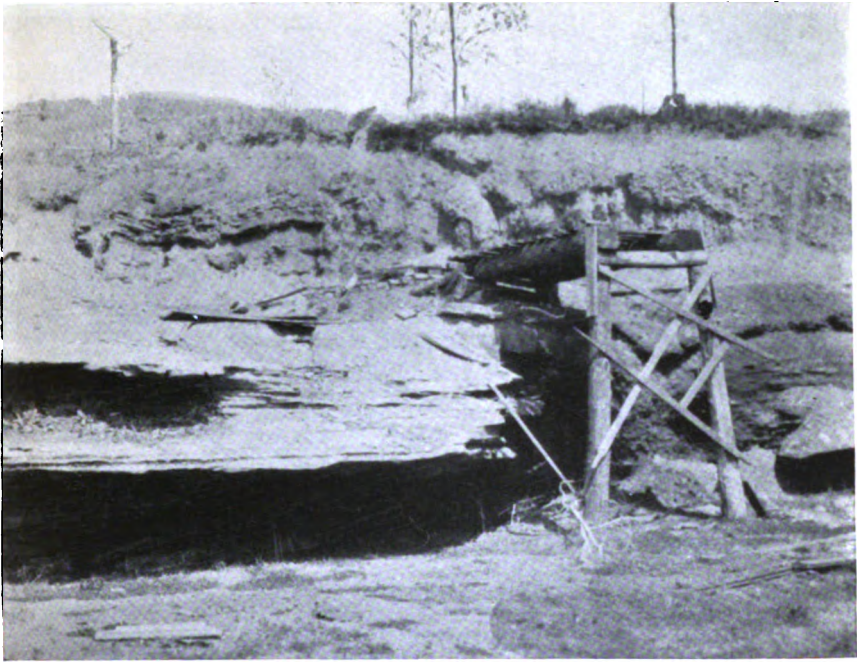


FIG. 1.—STRATUM OF PHOSPHATIC LIMESTONE OCCURRING IN PHOSPHATE BEDS.

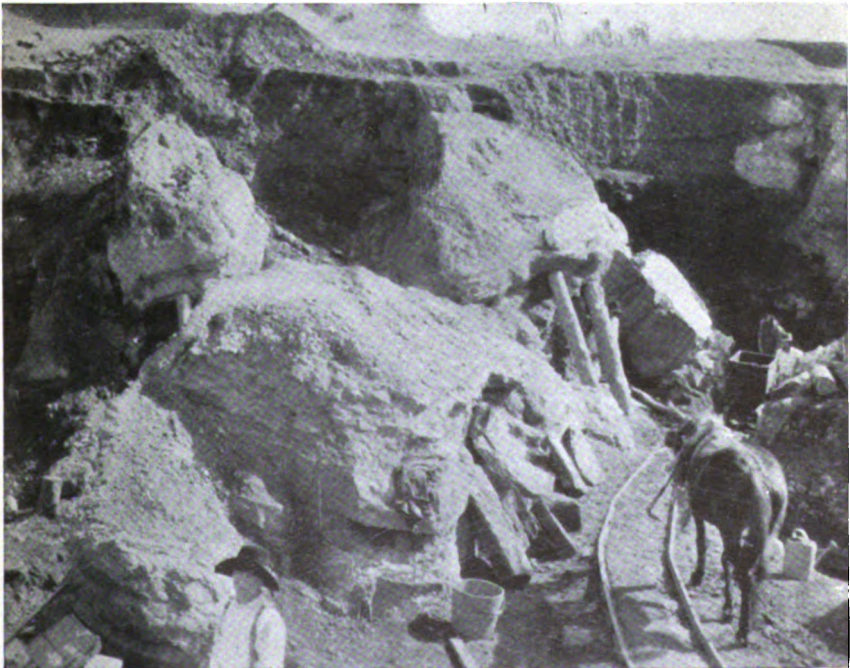


FIG. 2.—BROWN-ROCK MINING, SHOWING BOWLDERS OF PHOSPHATIC LIMESTONE.





FIG. 1.—BROWN-ROCK MINING, CENTERVILLE, HICKMAN COUNTY, TENN.



FIG. 2.—ONE OF THE MOST MODERN TYPES OF PHOSPHATE PLANTS, MOUNT PLEASANT, TENN.





FIG. 1.—BROWN-ROCK PHOSPHATE PLANT, SHOWING WASTE POND IN FOREGROUND.



FIG. 2.—ANOTHER VIEW OF THE SAME PLANT, SHOWING HOOD OVER STACK AND SETTLING TANKS FOR FINELY DIVIDED PHOSPHATE.







BLUE-ROCK MINE, 2½ MILES SOUTHEAST OF CENTERVILLE, HICKMAN COUNTY, TENN.



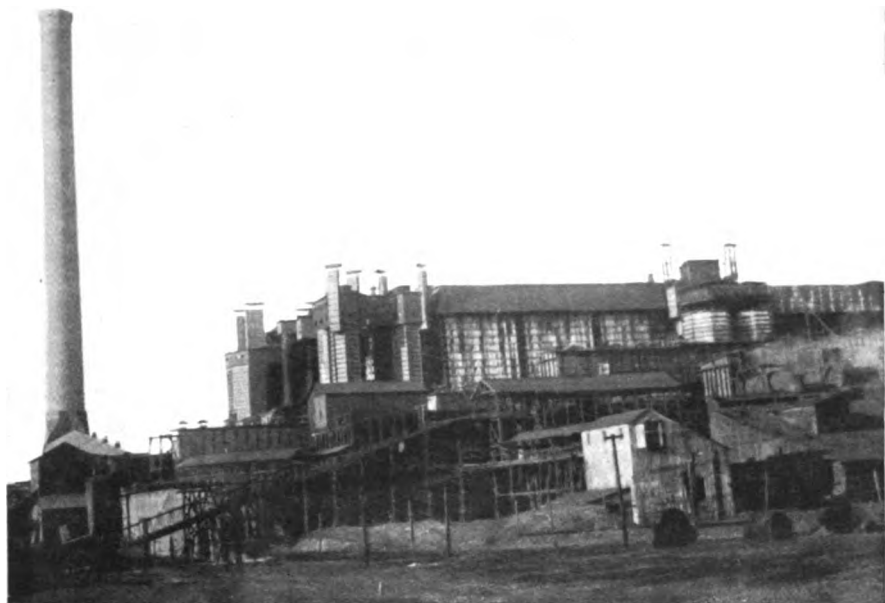


FIG. 1.—FRONT VIEW OF ACID PLANT RUN IN CONNECTION WITH A COPPER MINE.

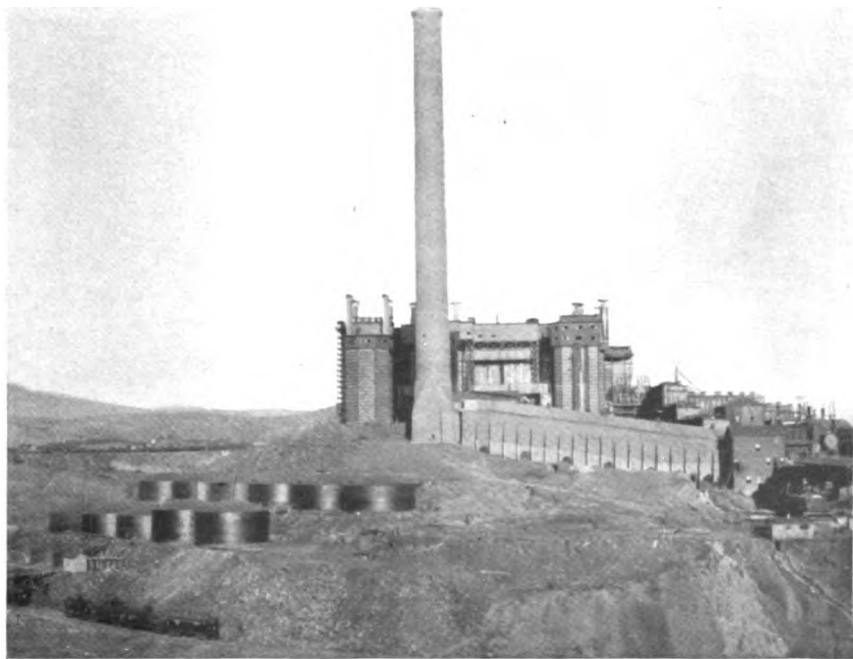


FIG. 2.—SIDE VIEW OF SAME PLANT, SHOWING STORAGE TANKS FOR ACID.





FIG. 1.—BATTERY OF PYRITES BURNERS.



FIG. 2.—SULPHURIC ACID PLANT STORAGE SHED AND CINDER PILE.



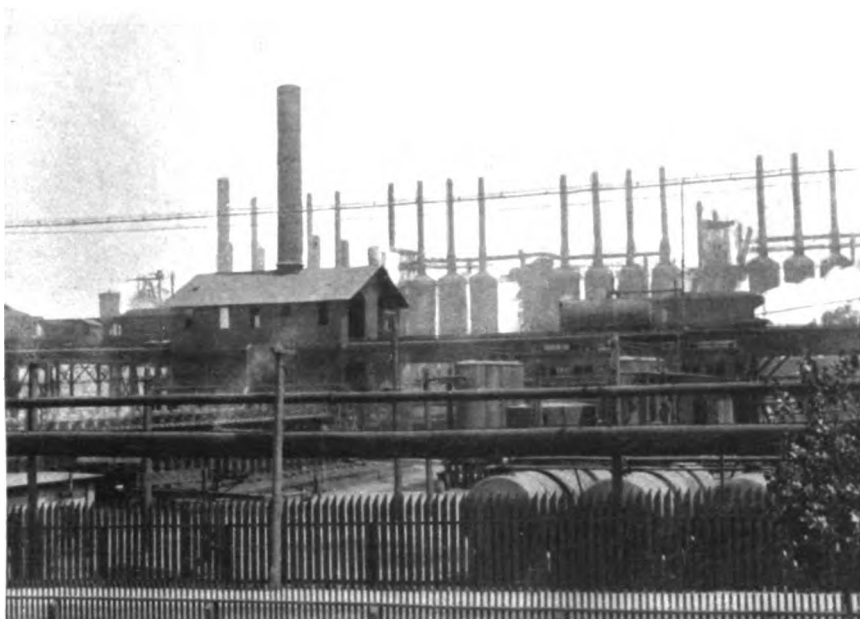


FIG. 1.—VIEW OF MODERN BY-PRODUCT COKE-OVEN PLANT WITH IRON FURNACE IN BACKGROUND.

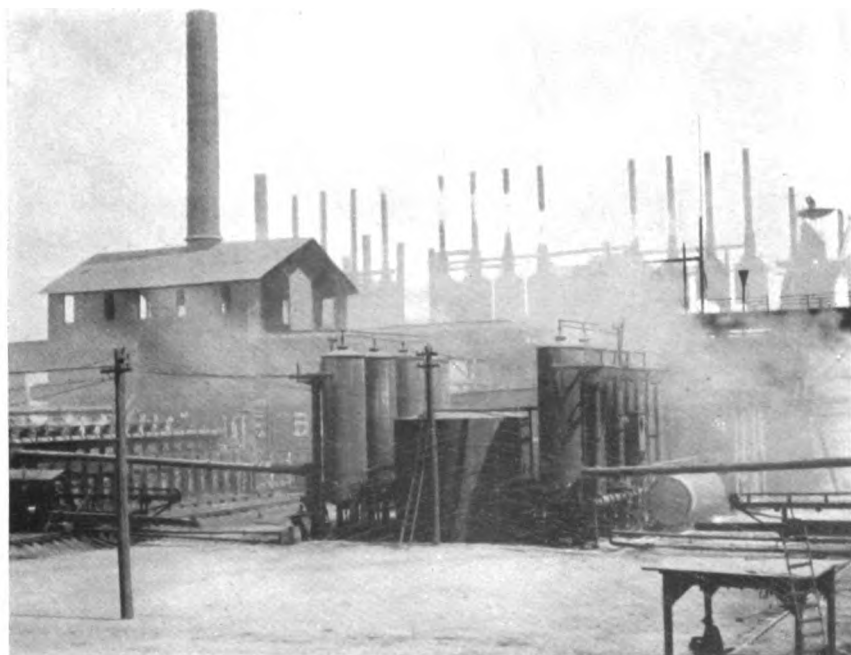


FIG. 2.—A NEARER VIEW OF THE SAME PLANT.





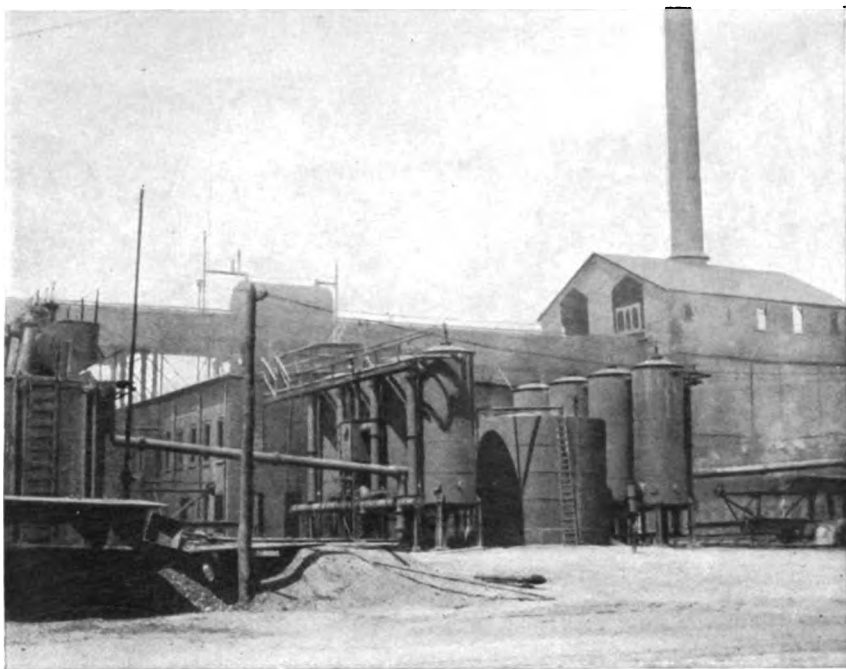


FIG. 1.—VIEW OF TAR AND LIQUOR CONDENSERS.



FIG. 2.—BY-PRODUCT HOUSE CONTAINING AMMONIA STILLs.





FIG. 1.—BED OF NEREOCYSTIS (BLADDER KELP) AT KANAKA BAY.



FIG. 2.—NEREOCYSTIS PLANTS AT LOW TIDE, TURN ISLAND.





FIG. 1.—A ROCK NEAR TURN ISLAND AT LOW TIDE.

[The two men are holding a *Nereocystis* plant. The rocks on which they are standing are covered with *Alaria*.]

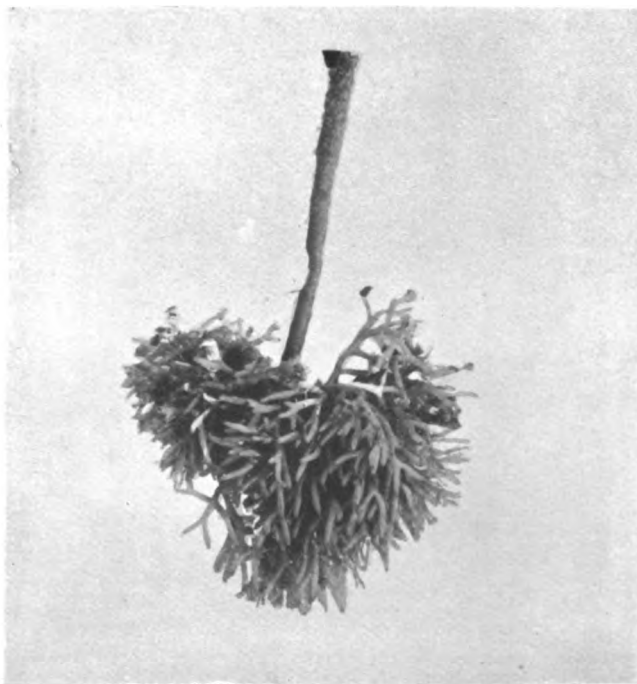
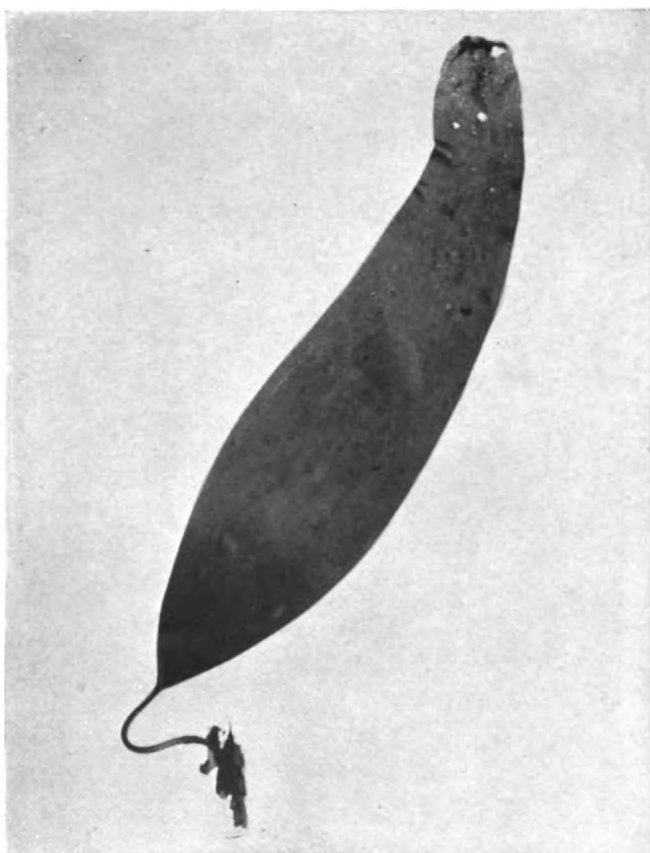


FIG. 2.—A HOLDFAST OF NEREOCYSTIS.





**A YOUNG NEREOCYSTIS PLANT.**

[The pneumatocyst has not yet formed and the frond has not yet begun to divide.]





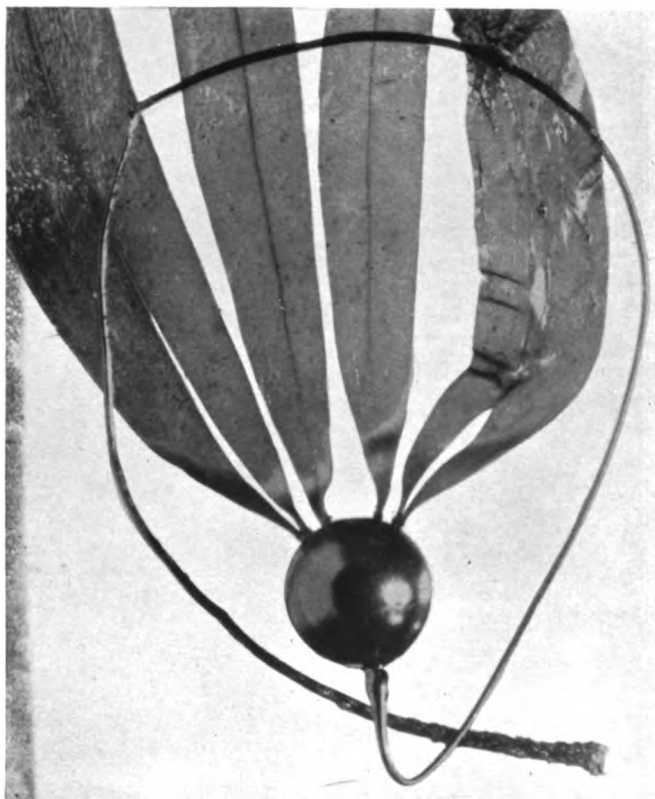


FIG. 1.—A YOUNG NEREOCYSTIS PLANT, SHOWING PNEUMATOCYST AND BASAL SPLITTING OF LEAVES.

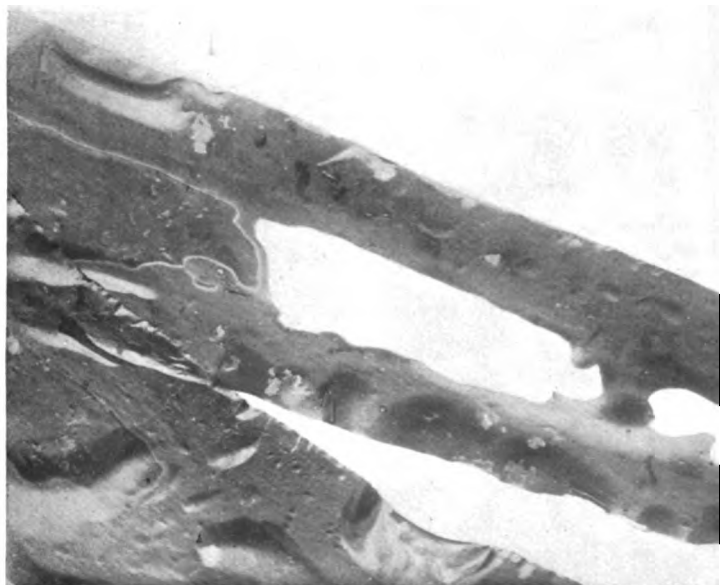


FIG. 2.—PORTIONS OF TWO FRONDS OF NEREOCYSTIS.

[A soral patch is seen at the left side of the upper one. At the right a soral patch has fallen out.]





FIG. 2.—LAMINARIA BULLATA.



FIG. 1.—LAMINARIA SACCHARINA.





FIG. 2.—*AGARUM FIMBRIATUM*.

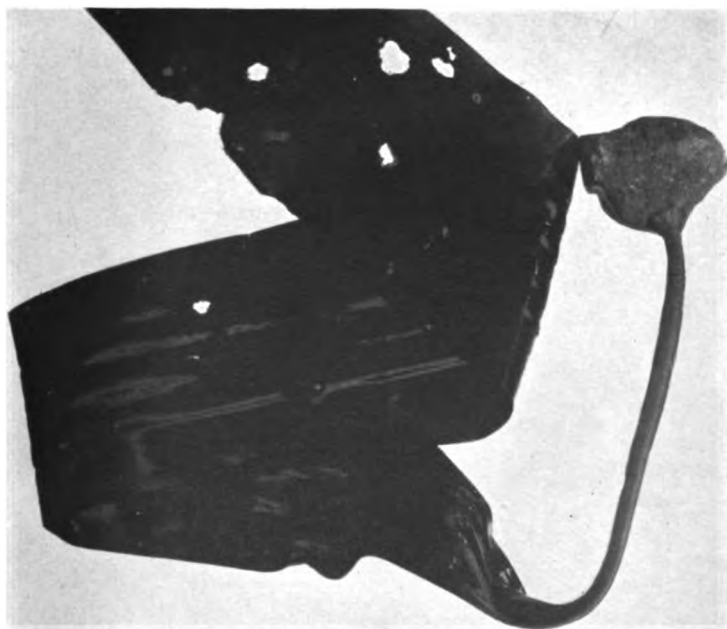


FIG. 1.—A FOLDED PLANT OF *CYNATHAERE TRIPLICATA*.





FIG. 1.—HEDOPHYLLUM ON ROCK AT NEAH BAY.

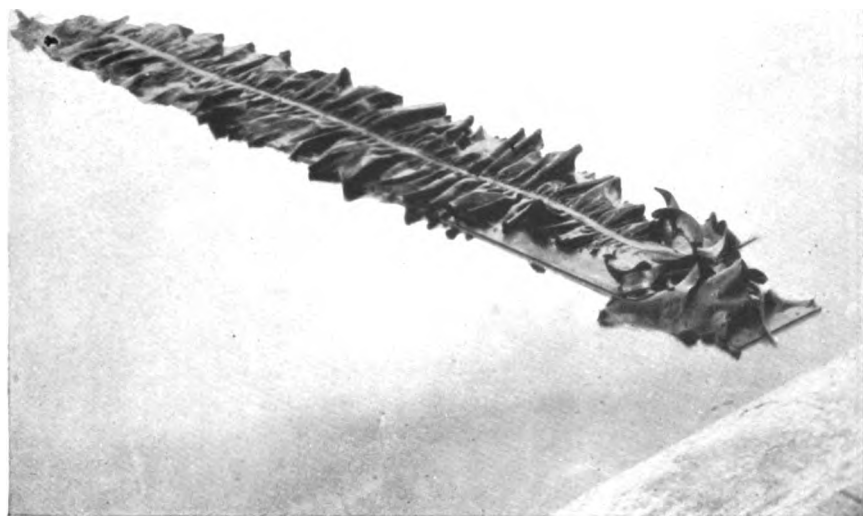


FIG. 2.—AN ALARIA PLANT FLOATED ON A BOARD.

It was attached to the log at the right.





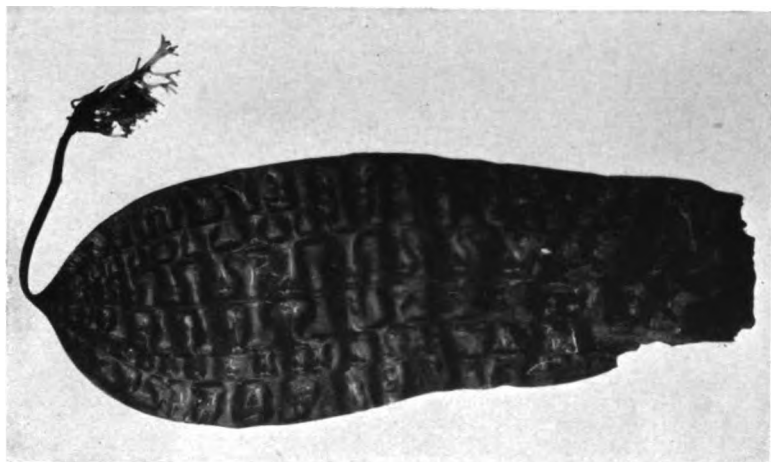


FIG. 1.—*COSTARIA TURNERI*.



FIG. 2.—*PLEUROPHYCUS GARDNERI*.





FIG. 1.—MAN HOLDING A SINGLE EGREGIA PLANT AT KANAKA BAY, AT LOW TIDE.  
[The rock on which he is standing is covered with Hedophyllum.]



FIG. 2.—FUCUS ON A ROCK AT KANAKA BAY.  
[Wide fucus on the right, narrow fucus on the left.]



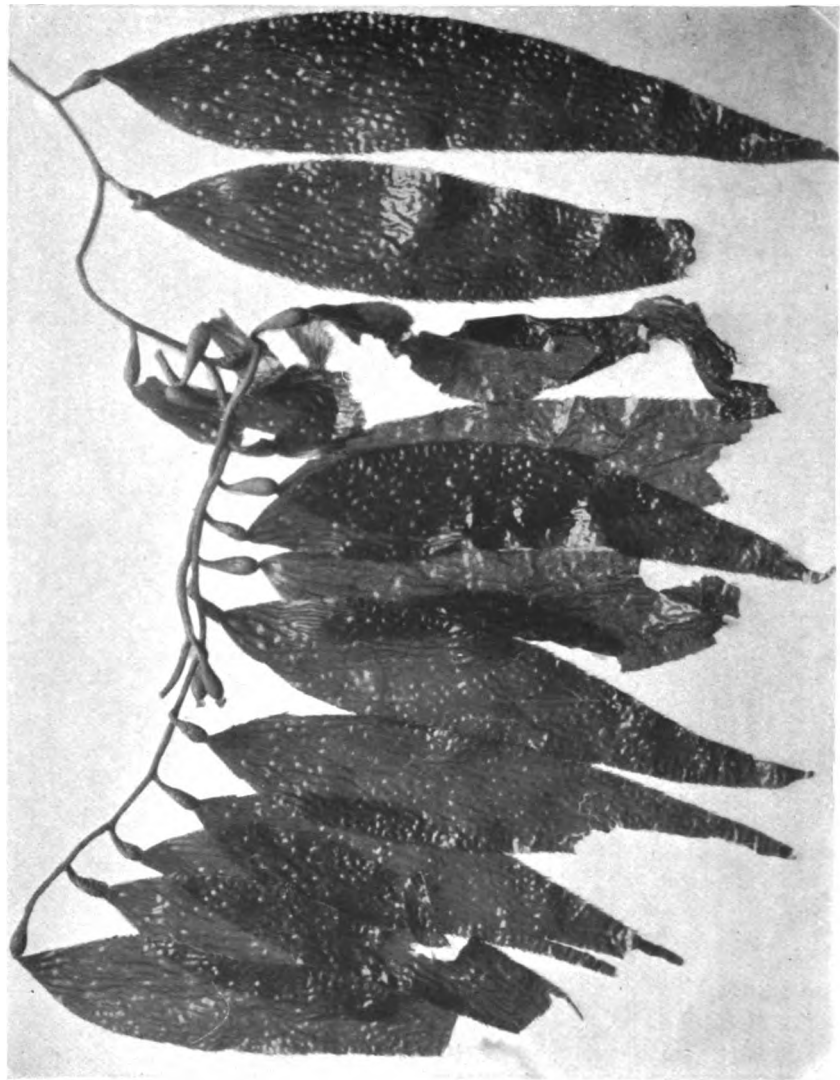


FIG. 1.—PORTION OF AN EGREGIA PLANT, SHOWING SPOROPHYLLS AND FLOATS.



FIG 2.—CODIUM MUCRONATUM.

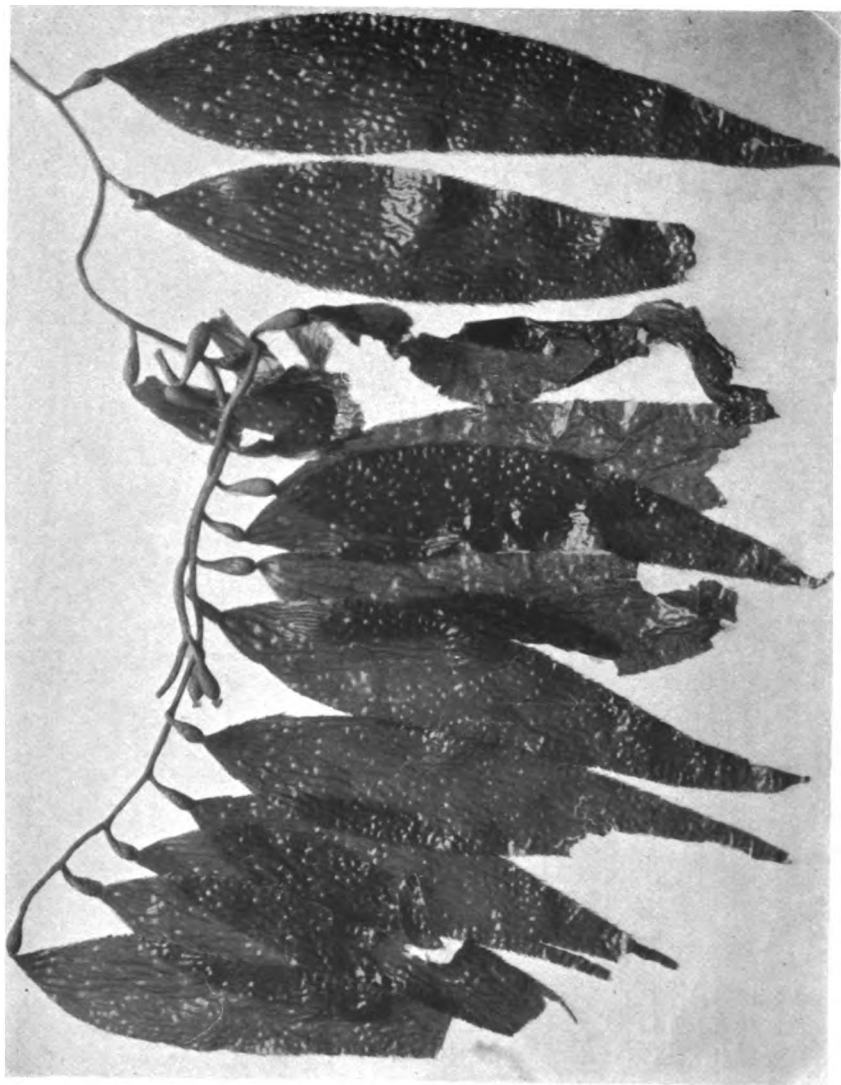




MACROCYSTIS PYRIFERA FROM SOUTHERN CALIFORNIA.

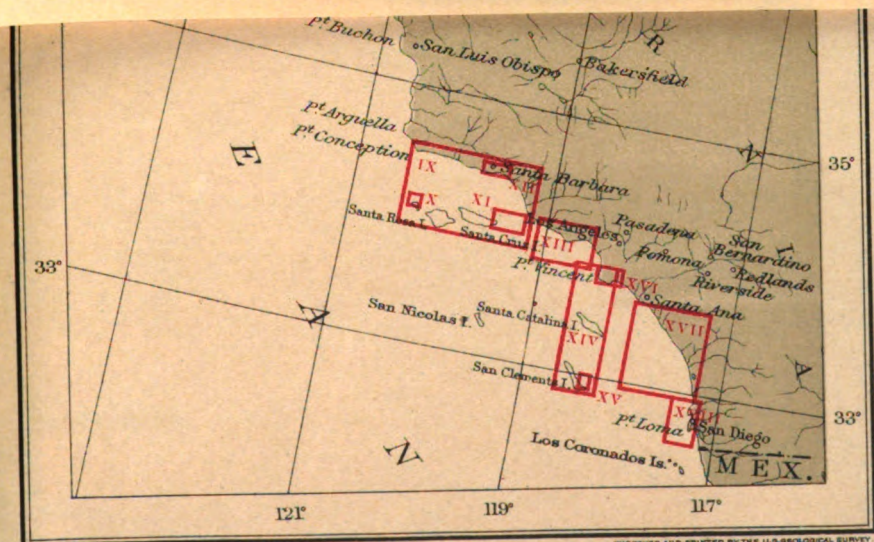






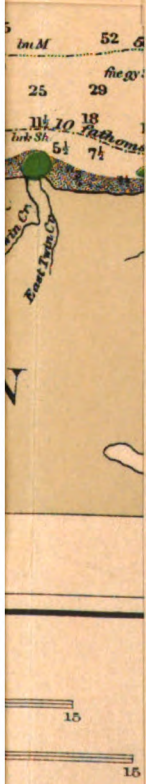
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Mapped  
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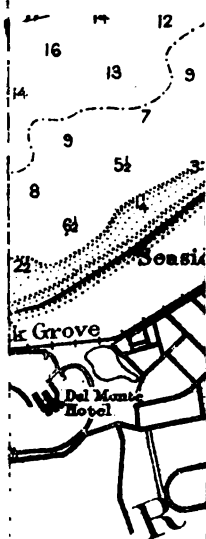
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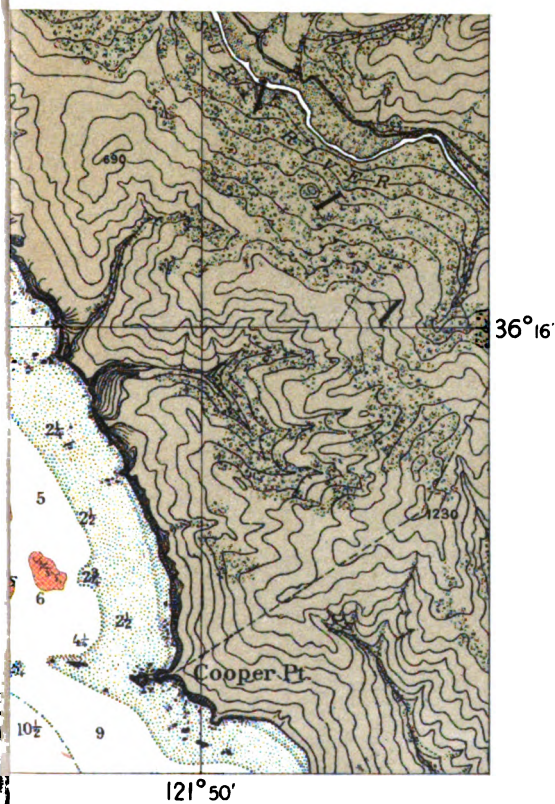












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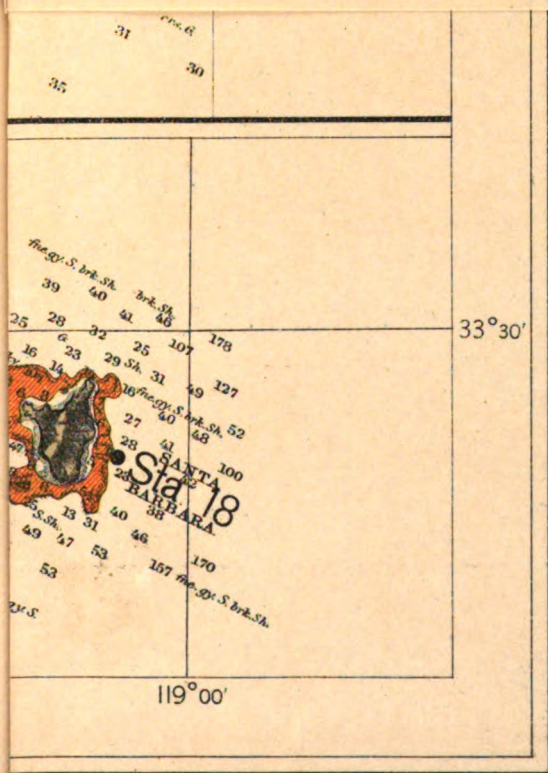
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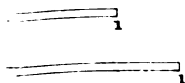
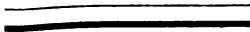
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